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Improved Emission Factors for Fugitive Dust from Western Surface Coal Mining Sources

PEDCo-Environmental, Inc., Kansas City, MO

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IMPROVED EMISSION FACTORS FOR FUGITIVE DUST FROM WESTERN SURFACE COAL MINING SOURCES

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16. ABSTRACT

The primary purpose of this study was to develop emission factors for significant surface coal mining operations that are applicable at Western surface coal mines and are based on state-of-the-art sampling and data analysis procedures. Primary objectives were 1) to develop emission factors for individual mining operations, in the form of equations with several correction factors to account for site-specific conditions, and 2) to develop these factors for particles less that 2.5μm (fine particulates), particles less than 15 μm (inhalable particulates), and total suspended particulates. Secondary objectives were 1) to determine deposition rates over the 50- to 100-m distance downwind from the sources, and 2) to estimate control efficiencies for certain source categories. Emissions resulting from the following were sampled at three mines during 1979 and 1980: drilling, blasting, coal loading, bulldozing, dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas. The primary sampling methods was exposure profiling, supplemented by upwind/downwind, ballon, wind tunnel, and quasi-stack sampling. The number of tests run totaled 265.

The report concludes with a comparison of the generated emission factors with previous ones, a statement regarding their applicablitity to mining operations with specific caveats and collateral information which must be considered in their use and recommendations for additional research in Western and other mines.

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati, (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This project involved the development of emission factors for operations at surface coal mines located in the western United States. Operations sampled included, but were not limited to, haul road traffic, scrapers, draglines, and blasts. Sampling techniques used included exposure profiling, upwind-downwind and wind tunnel testing. From this information, emission factors were developed which take into account such characteristics as soil moisture and silt content. The data presented in this study should aid both private industry and government agencies in evaluating emissions from coal mining operations. If additional information is needed, contact the Oil Shale and Energy Mining Branch of the Energy Pollution Control Division.

David G. Stephan
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ABSTRACT

Since 1975 several sets of emission factors have evolved for estimating fugitive dust emission from surface coal mines. The diverse values of available emission factors, obvious sampling problems, and questions of applicability over a range of mining/meteorological conditions have undermined confidence in air quality analyses performed to date. By early 1979, these problems led to a ground swell of support, from both regulatory and mining industry personnel, for the development of new emission factors.

This study began in mid-March of 1979. The primary purpose of this study was to develop emission factors for significant surface coal mining operations that are applicable at Western surface coal mines and are based on state-of-the-art sampling and data analysis procedures. The primary objectives have been 1) to develop emission factors for individual mining operations, in the form of equations with several correction factors to account for site-specific conditions; and 2) to develop these factors in three particle size ranges--less than 2.5 μm (fine particulates), less than 15 μm (inhalable particulates), and total suspended particulates. Secondary objectives were 1) to determine deposition rates over the 50- to 100-m distance downwind from the source, and 2) to estimate control efficiencies for certain source categories.

Sampling was performed at three mines during 1979 and 1980. Emissions resulting from the following were sampled: drilling (overburden), blasting (coal and overburden), coal loading, bulldozing (coal and overburden), dragline operations, haul trucks, light- and medium-duty trucks, scrapers, graders, and wind erosion of exposed areas (overburden and coal). The primary sampling method was exposure profiling. When source configuration made it necessary, this method was supplemented by upwind/downwind, balloon, wind tunnel, and quasi-stack sampling. A total of 265 tests were run. Extensive quality assurance procedures were implemented internally for this project and were verified by audit.

Size-specific emission factors and correction parameters were developed for all sources tested. Confidence intervals and probability limits were also calculated. Additional data for determination of deposition rates were gathered, but no algorithms could be developed. Two control measures for unpaved roads were tested.

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The report concludes with a comparison of the generated emission factors with previous ones, a statement regarding their applicability to mining operations with specific caveats and collateral information which must be considered in their use, and recommendations for additional research in Western and other mines.

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ABBREVIATIONS OF UNITS

ABBREVIATIONS

ug/m^3	micrograms per standard cubic meter
mg	milligrams
SCFM	standard cubic feet per minute
min	minutes
°C	degrees celsius
in.	inches
ACFM	actual cubic feet per minute
ft	feet
fpm	feet per minute
sfpm	standard feet per minute
cm	centimeters
m	meters
lb	pounds
VMT	vehicle miles traveled
s	seconds
°k	degrees kelvin
g	grams
yd^3	cubic yards
BTu	British Thermal Units
gal	gallons
mi	miles
CFM	cubic feet per minute
mph	miles per hour

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SECTION 1

INTRODUCTION

PRE-CONTRACT STATUS OF MINING EMISSION FACTORS

Over the past 4 or 5 years, several sets of emission factors for estimating fugitive dust emissions from surface coal mining have evolved. The first of these were primarily adaptations of published emission factors from related industries, such as construction, aggregate handling, taconite mining, and travel on unpaved roads (Monsanto Research Corporation 1975; Environmental Research and Technology 1975; PEDCo Environmental 1975; Chalekode 1975; PEDCo Environmental 1976; Wyoming Department of Environmental Quality 1976, Appendix B; U.S. Environmental Protection Agency 1977a; Colorado Department of Health 1978; Midwest Research Institute 1978).

The concept of developing emission factors by operation rather than for the entire mine has been widely accepted from the beginning. This approach recognizes the large variation in operations from mine to mine.

As demand for emission factors specifically for surface coal mining increased, some sampling studies at mines were undertaken. The first of these, sponsored by EPA Region VIII in the summer of 1977, sampled 12 operations at 5 mines in a total of 213 sampling periods (U.S. Environmental Protection Agecny 1978a). Emission factors were reported by operation and mine, but no attempt was made to derive a general or "universal" emission factor equation for each operation that could be applied outside the five geographic areas where the sampling took place. Also, several problems with the upwind-downwind sampling method as employed in the study were noted in the report and by the mining industry observers. An industry-sponsored sampling study was conducted at mines in the Powder River Basin in 1978-1979. No information or proposed emission factors from that study have been released yet.

EPA Region VIII and several state agencies have evaluated the available emission factors and compiled different lists of recommended factors for use in their air quality analyses (U.S. Environmental Protection Agency 1979; Wyoming Department of Environmental Quality 1979; Colorado Department of Health 1980). Some of the alternative published emission factors vary by an order of magnitude. Part of this variance is from actual difference in average emission rates at different mines (or at different times or locations within a single mine) due to meteorological conditions, mining equipment/techniques being used, control techniques being employed, and soil characteristics.

The diverse values for available emission factors, the obvious problems encountered in sampling mining sources, and questions of applicability over a range of mining/meteorological conditions have all undermined confidence in air quality analysis done to date. These problems led to a ground swell of support from regulatory agency personnel in early 1979 for new emission factors.

The major steps in an air quality analysis for a mine are estimating the amount of emissions and modeling to predict the resulting ambient concentrations. The preamble to EPA's Prevention of Significant Deterioration (PSD) regulations notes the present inability to accurately model the impact of mines and indicates that additional research will be done. However, problems in modeling of mines have been overshadowed by concern over the emission factors. Advancement in this entire area seems to be contingent on the development of new emission factors.

PURPOSE OF STUDY

The purpose of this study is to develop emission factors for significant surface coal mining operations that are applicable at all Western mines and that are based on widely acceptable, state-of-the-art sampling and data analysis procedures. Confidence intervals are to be developed for the emission factors, based on the numbers of samples and sample variance. The present study is to be comprehensive enough so that an entire data base can be developed by consistent methods, rather than just providing some additional data to combine with an existing data base. The emission factors are to be in the form of equations with several correction factors, so values can be adjusted to more accurately may also be used as the means to combine similar emission factors (e.g., haul roads and unpaved access roads), if the data support such combinations.

The emission factors are to be generated for three size ranges of particles--less than 2.5 μm (FP), less than 15 μm (IP), and total suspended particulate (TSP). An alternative to the TSP size fraction consists of suspended particles less than 30 μm (SP); the upper size limit of 30 μm is the approximate effective cutoff diameter for capture of fugitive dust by a standard high volume particulate sampler (Wedding 1980).

Definition of particle sizes is important for at least three reasons: deposition rates in dispersion modesl are a function of particle size; EPA may promulgate size-specific ambient air quality standards in the near future; and visibility analyses require information on particle size distribution.

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The study is also intended to determine deposition (or plume depletion) rates over the 50 to 100 m distance immediately downwind of the sources. Although it is recognized that deposition continues to significant for distances of a few kliometers, a large percentage of the fallout occurs in the first 100 m and estimates of the additional deposition can be made more accurately from particle size sampling data than from measurements associated with the emission factor development.

A secondary purpose is to estimate the efficiencies of commonly used dust control techniques at mines, such as watering and chemical stabilization of haul roads. This aspect of the study received less emphasis as the study progressed as better information indicated that more test periods than originally anticipated would be needed to determine the basic emission factors with a reasonable margin of error.

The study was designed and carried out with special effort to encourage input and participation by most of the expected major users of mining emission factors. The intent was to obtain suggestions for changes and additions prior to developing the emission factors than criticism of the techniques and scope of the study afterward.

TECHNICAL REVIEW GROUP FOR THE STUDY

Participants

EPA's Office of Air Quality Planning and standards (OAQPS) took the initial lead in planning for a study to develop new emission factors. Their staff became aware of the amount of concern surrounding the available mining factors when they considered including surface mining as a major source category under proposed regulations for Prevention of Significant Deterioration.

EPA Region VIII Office, which had directed the first fugitive dust sampling study at surface mines and published a compilation of recommended mining emission factors, immediately encouraged such a study and offered to provide partial funding. The new created Office of Surface Mining (OSM) in the Department of Interior also offered support and funding. At that time, OS, had just proposed regulations pursuant to the Surface Mining Control and Reclamation Act (SMCRA) requiring air quality analyses for Western mines of greater than 1,000,000 tons/yr production (this requirement was dropped in the final regulations).

EPA's Industrial Environmental Research Laboratory (IERL) soon became involved as a result of its responsibilities for the agency's research studies on mining. This group already had planned some contract work on

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fugitive dust emissions from surface coal mines in its FY/1979 budget, so its staff assumed the lead in contractual matters related to the study.

All the early participants agreed that even broader representation would be desirable in the technical planning and guidance for the study. Therefore, a technical review group was established at the outset of the study to make recommendaitons on study design, conduct, and analysis of results. The agencies and organizations represented on the technical review group are shown in Table 1-1. This group received draft materials for comment and met periodically throughout the study. Other groups that expressed an interest in the study were provided an opportunity to comment on the draft report.

Study Design

The study design was the most important component of the study from many perspectives. It was the primary point at which participants could present their preferred approaches. The design also had to address the problems that had plagued previous sampling studies at mines and attempt to resolve them. Most of the decision making in the study was done during this phase.

The first draft of the study design report was equivalent to a detailed initial proposal by the contractors, with the technical review group then having latitude to suggest modifications or different approaches. The rationales for most of the design specifications were documented in the report so members of the technical review group would also have access to the progression of thinking leading to recommendations.

The scope of the full study was not fixed by contract prior to the design phase. Some of the options left open throughout the design phase were number of mines, geographical areas, different mining operations, and the seasonal range to be sampled. In some cases, the final decision on recommended sampling methods was left to the results of comparative testing--alternative methods were both used initially until the results could be evaluated and the better method retained.

Several major changes were made from the first draft to the third (final) draft of the study design. These changes are summarized in Section 3. In addition, requests were made for in-depth analyses on particular aspects of the study design that were responded to in separate reports. Specifically, the separate reports and their release dates were:

Error Analysis for Exposure Profiling	October 1979
Error Analysis for Upwind-Downwind Sampling	October 1979

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TABLE 1-1. TECHNICAL REVIEW GROUP FOR MINING STUDY

Organization	Representative	Alternate
Bureau of Land Management	Stan Coloff	
Bureau of Mines (U.S.)	H. William Zeller	
Consolidation Coal Company	Richard Kerch	
Department of Energy, Policy Analysis Division	Suzanne Wellborn	Bob Kane
Environmental Protection Agency		
Industrial Environmental Research Lab.	Jonathan Herrmann	
Monitoring and Data Analysis Division	Thompson Pace	J. Southerland
Region VIII	E. A. Rachal	David Joseph
Source Receptor Analysis Branch	James Dicke	Edward Burt
Forest Service, U.S. Department of Agriculture	Douglas Fox	
National Coal Association	Charles T. Drevna	
National Park Service	Phil Wondra	J. Christiano
New Mexico Citizens for Clean Air and Water	Michael D. Williams	
North American Coal Corporation	Bruce Kranz	
Office of Surface Mining		
Headquarters	Robert Goldberg	
Region V	Floyd Johnson	
Peabody Coal Company	Steven Vardiman	
Wyoming Department of Environmental Quality	Randolph Wood	Chuck Collins

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Quality Assurance Procedures	October 1979
Example Calculations for Exposure Profiling	November 1979
Calculations Procedures for Upwind-Downwind Sampling Method	October 1979
Statistical Plan	November 1979
Statistica Plan, Second Draft	May 1980

The above reports were being prepared while sampling proceeded at the first two mines. The contents of these reports are summarized in this report in appropriate sections.

CONTENTS AND ORGANIZATION OF THIS REPORT

This report contains 16 sections and is bound in one volume. The first five sections describe the methodologies used in the study; e.g., sampling (Section 3), the sample analysis (Section 4), and data analysis (Section 5). Sections 6 through 11 present results of the various sampling efforts.

Sections 12 through 15 describe the evaluation and interpretation of results and the development of emission factor equations. The specific topics covered by section are:

12	Evaluation of Results
13	Development of Correction Factors and Emission Factor Equations
14	Evaluation of Emission Factors
15	Summary and Conclusions

Section 16 is the list of references.

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SECTION 2

SELECTION OF MINES AND OPERATIONS TO BE SAMPLED

GEOGRAPHICAL AREAS OF MOST CONCERN

The contract fo this study specified that sampling be done at Western surface coal mines. As a result of comments and recommendations made by members of the technical review group during the study design preparation, this restriction in scope was reviewed by the sponsoring agencies. The decision was made to continue focusing the study on Western mines for at least three reasons:

1. The Western areas are more arid than Eastern of Midwestern coal mining regions, leading to a greater potential for excessive fugitive dust emissions.

2. Western mines in general have larger production rates and therefore would be larger individual emission sources.

3. Most of the new mines, subject to analyses for environmental impacts, are in the West.

The need for emission factors for Eastern and Midwestern surface mines is certainly acknowledged. Consequently, an effort was made in the present study to produce emission factors that are applicable over a wide range of climatic and mining conditions.

There are 12 major coal field in the Western states (excluding the Pacific Coast and Alaskan fields), as shown in Figure 2-1. Together, they account for more than 64 percent of the surface-mineable coal reserves in the U.S. (U.S. Bureau of Mines 1977). The 12 coal fields have different characteristics which may influence fugitive dust emission rates from mining operations, such as:

Overburden and coal seam thickness and structure
Mining equipment commonly used
Operating procedures
Terrain
Vegetation
Precipitation and surface moisture
Wind speeds
Temperatures

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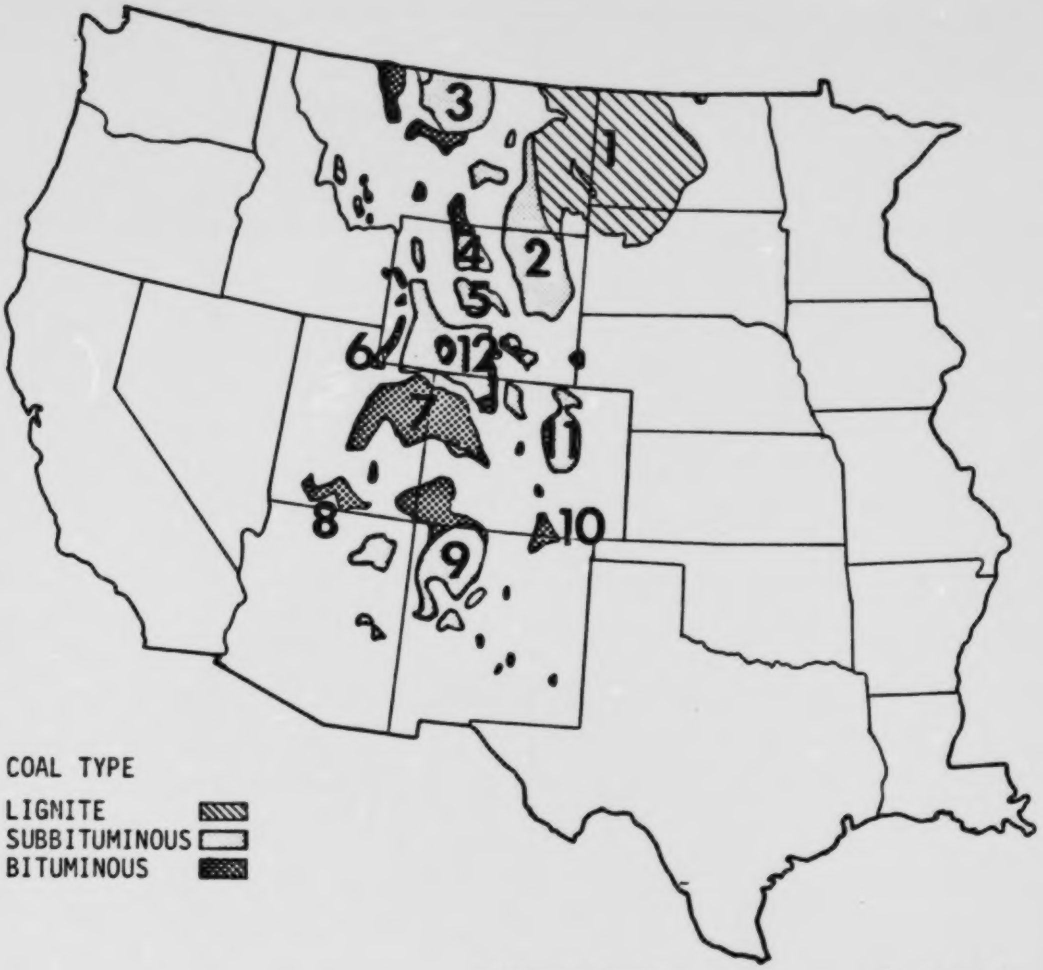

	Coal field	1978 production, 10^6 tons	Strippable reserves, 10^6 tons
1	Fort Union	14	23,529
2	Powder River	62	56,727
3	North Central	-	all underground
4	Bighorn Basin	-	all underground
5	Wind River	neg	3
6	Hams Fork	5	1,000
7	Uinta	2	308
8	Southwestern Utah	-	224
9	San Juan River	22	2,318
10	Raton Mesa	-	all underground
11	Denver	-	all underground
12	Green River	24	2,120

(Reference: U.S. DOE, Energy Information Administration. Bituminous Coal and Lignite Production and Mine Ops.-1978. Publication No. DOE/EIA-0118(78). Washington, D.C. June 1980.)

Figure 2-1. Coal fields of the Western U.S.

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Mines in all 12 Western coal fields could not be sampled in this study. The dual objectives of the emission factor development program were to sample representative, rather than extreme, emission rates and yet sample over a wide range of meteorological and mining conditions so that the effects of these variables on emission rates could also be determined. Therefore, diversity was desired in the selection of mines (in different coal fields) for sampling.

No formal system was developed for quantifying the diversity between the Western fields. Instead, three fields with high production from surface mines and distinctly different characteristics were identified by the project participants: Fort Union (lignite), Powder River Basin, and San Juan River. Sampling at mines in each of these fields was to be the first priority. If sampling in a fourth field were possible or a suitable mine could not be located in one of the three primary areas, the Green River field was the next choice.

SIGNIFICANT DUST-PRODUCING OPERATIONS

All of the mining operations that involve movement of soil, coal, or equipment or exposure of erodible surfaces generate some amount of fugitive dust. Before a sampling program could be designed, it was first necessary to identify which of the many emission-producing operations at the mines would be sampled.

The operations at a typical Western surface mine are shown schematically in Figure 2-2. The initial mining operation is removal of topsoil and subsoil with large scrapers. The topsoil is carried by the scrapers to cover a previously mined and regraded area (as part of the reclamation process) or placed in temporary stockpiles. The exposed overburden is then leveled, drilled, and blasted. Next, the overburden material is removed down to the coal seam, usually by dragline or shovel and truck operation. It is placed in the adjacent mined cut and forms a spoils pile. The uncovered coal seam is then drilled and blased. A shovel or front-end loader loads the borken coal into haul trucks. The coal is transported out of the pit along graded haul roads to the tipple, or truck dump. The raw coal may also be dumped on a temporary storage pile and later rehandled by a front-end loader or dozer.

At the tipple, the coal is dumped into a hopper that feeds the primary crusher. It is then moved by conveyor through additional coal preparation equipment, such as secondary crushers and screens, to the storage area. If the mine has open storage piles, the crushed coal passes through a coal stacker onto the pile. The piles are usually worked by dozers, and are subject to wind erosion. From the storage area, the coal is conveyed to the train loading facility and loaded onto rail cars. If the mine is captive, coal goes from the storage pile to the power plant.

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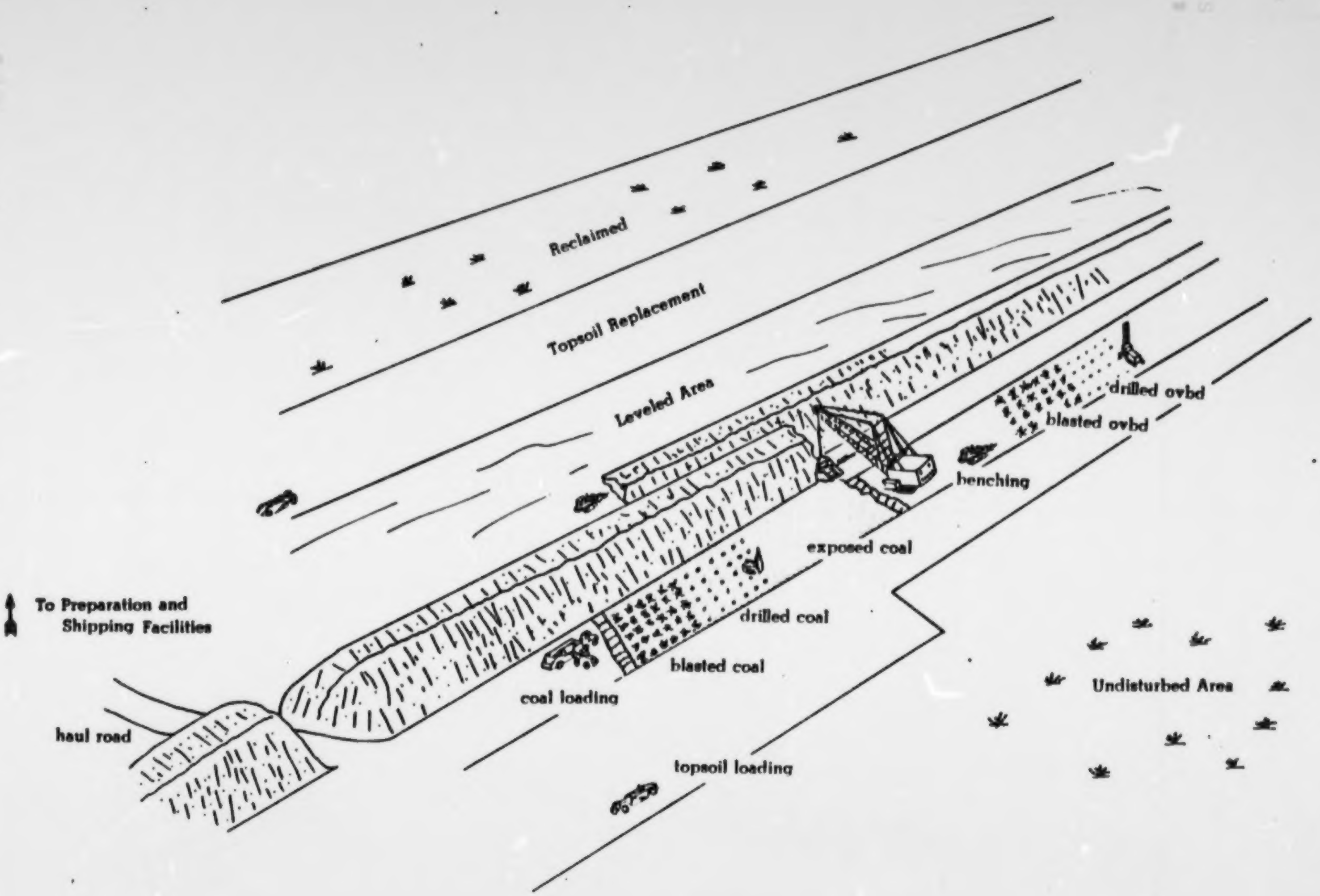
Reclaimed
Topsoil Replacement
Leveled Area
drilled ovbd
blasted ovbd
benching
exposed coal
drilled coal
blasted coal
coal loading
topsoil loading
Undisturbed Area
haul road
To Preparation and Shipping Facilities

Figure 2-2. Operations at typical western surface coal mines.

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During mine reclamation, which proceeds continuously throughout the life of the mine, overburden spoils piles are smoother and shaped to predetermined contours by dozers. Topsoil is placed on the graded spoils and the land is prepared for revegetation by furrowing, mulching, etc. From the time an area is disturbed until the new vegetation emerges, the exposed surfaces are subject to wind erosion.

These operations could not be ranked directly in order of their impact on particulate air quality because reliable emission factors to estimate their emissions do not exist. Also, any specific mine would probably not have the same oeprations as the typcial mine described above, and the relative magnitudes of the operations vary greatly from mine to mine (e.g., the average haul distance from the pit to the tipple).

In the study design phase, two different analyses were done to evaluate the relative impacts of the emission sources (PEDCo Environmental and Midwest Research Institute 1979). In the first analysis, several alternative emission factors reported in the literature were used to calculate estimated emissions from a hypothetical mine having all the possible mining sources described above. The second analysis used a single set of emission factors, judged to be the best available for each source, combined with activity data from seven actual surface mines in Wyoming and Colorado. The resulting rankings from the two analyses were similar. The ranges of percentages of total mine emissions estimated by the two analyses are summarized in Table 2-1. The sources are listed in the table in order of decreasing estimated contribution.

A one percent contribution to total mine emissions was used in the study design to separate significant sources, for which sampling would be performed, from insignificant sources. There were only a few sources for which classification was questionable: draglines and wind erosion of storage piles. This conflict arose because one analysis showed them to be insignificant and the other indicated they were significant. Because these operations are integral parts of most mine operations and there was a wide disparity between alternative emission factors, they were both included as significant sources to be sampled.

The ranking was also considered in determining the number of tests for each source--more tests were allocated to sources predicted to be the major contributors.

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TABLE 2-1. DETERMINATION OF SIGNIFICANT DUST-PRODUCING OPERATIONS

Operation	Primary emission composition	Range in % of total mine emissions
Significant sources		
Haul truck	soil	18-85
Light and medium duty vehicles (unpaved access roads)	soil	<1-27
Shovel/truck loading, ~~ovb~~ overburden	soil	4-12
Shovel/truck loading, coal	coal	<1-11
Dozer operations	either	4-11
Wind erosion of exposed areas	soil	<1-10
Scraper travel	soil	<1- 8
Blasting, ~~ovb~~ overburden	soil	<1- 5
Blasting, coal	coal	<1- 4
Drilling, ~~ovb~~ overburden	soil	<1- 4
Front-end loader	coal	1- 3
Grader	soil	1- 3
Dragline	soil	<1- 2
Wind erosion of storage piles	coal	<1- 2
Insignificant sources		
Truck dumping, ~~ovb~~ overburden	soil	<1
Truck dumping, coal	coal	<1
Scraper pickup	soil	<1
Scraper spreading	soil	<1
Coal stacker	coal	<1
Train loading	coal	<1
Enclosed storage loading	coal	<1
Transfer/conveying	coal	<1
Vehicle traffic on paved roads	soil	<1
Crushing, primary	coal	<1
Crushing, secondary	coal	<1
Screening and sizing	coal	<1
Drilling, coal	coal	<1

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POTENTIAL MINES FOR SAMPLING

The number of mines to be sampled was set at three in the study design. This was based on a compromise between sampling over the widest range of mine/meteorological conditions by visiting a large number of mines and obtaining the most tests within the budget and time limits by sampling at only a few mines. The criteria for selection of appropriate mines were quite simple:

1. The three mines should have the geographical distribution described above, i.e., one each in the Fort Union, Powder River Basin, and San Juan River fields.
2. Each mine should have all or almost all of the 14 significant dust-producing operations listed in Table 2-1.
3. The mine personnel should be willing to cooperate in the study and provide access to all operations for sampling.
4. The mines should be relatively large so that there are several choices of locations for sampling each of the operations.

Using their industry contacts, the National Coal Association (NCA) members did preliminary screening to find appropriate mines and made contacts to determine whether suitable mines were interested in participating in the sampling program.

The three mines finally selected were each obtained in a different manner. The first, in the Powder River Basin, volunteered before any contacts were made with mining companies. The second mine was operated by a company with a representative on the technical review group. This mine was in the Fort Union field in North Dakota. By coincidence, these first two mines were among the five where sampling had been done in the previous EPA-sponsored emission factor development study (EPA 1978a).

Several mines in the San Juan River field were contacted by NCA and by PEDCo to participate. After failing to obtain a volunteer, provisions of the Clean Air Act were invoked to obtain access. Personnel at the third mine cooperated fully with the sampling teams and were very helpful.

The names of the three mines are not mentioned in this report. Pertinent information on the three mines is summarized in Table 2-2.

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TABLE 2-2. CHARACTERISTICS OF MINES THAT WERE SAMPLED

Parameter	Units	Mine 1	Mine 2	Mine 3
Location		Powder River Basin	North Dakota	Four Corners
Production	10^6 tons	9-12	1-4	5-8
Stratigraphic data				
Typical overburden depth	ft	75	35	80
Typical coal seam thickness	ft	23	2, 4, 9	8
Typical parting thickness	ft	-	2, 15, 30	35
Typical pit depth	ft	98	80	145
Av overburden density	lb/yd^3	3000	3350	5211
Operating data				
No. of active pits	-	3	2	7
Typical haul distance (one way)	mi	1.6	3.5	2.5
Av storage pile size	10^3 tons	72	15	300
Equipment				
Draglines	No.;yd^3	3; 60	2; 33, 65	4; 38-64
Shovels	No.;yd^3	4; 17, 24	2; 15	1; 12
Front-end loaders	No.;yd^3	4; 5-12.5	1; 12	6; 23.5
Haul trucks	No.;tons	13; 100, 120	6; 170	11; 120, 150
Water trucks	No.;10^3 gal	5; 8, 10	3; 1, 8	2; 24
Scrapers	No.;yd^3	6; 22	12; 33, 40	3; 34
Dozers	No.	9	8	9
Av coal analysis data				
Heat value	Btu/lb	8600	10600	7750
Sulfur content	%	0.8	0.75	0.75
Moisture content	%	25	37	13

Information in this table provided by respective mining companies.

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SCHEDULE

A task order was issued in mid-March, 1979, to prepare a preliminary study design for development of surface coal mining emission factors. The time period for the task order was 8 weeks (to mid-May). If the resulting sampling methods and analytical approach were acceptable to the sponsoring agencies and the technical review group being convened to guide the study and assure its wide applicability, another contract to perform the sampling and data analysis was to follow immediately so that field work could be completed during the summer and fall of 1979.

The first mine was sampled on schedule, from July 23 through August 24, 1979. However, delays in obtaining approval to sample at a second mine; requests for further documentation of calculation procedures, error analyses, and quality assurance procedures; and preparation of a detailed statistical plan caused a slip in the schedule at this point. The second mine was sampled from October 10 through November 1, 1979, precluding a sampling period at a third mine during the dusty season. The winter sampling at the first mine took place from December 4 through 13, 1979.

Sampling at the third mine, rescheduled for the spring of 1980, was postponed on several occasions for such reasons as: lapse of the primary contract with the need to find an alternative contracting mechanism; unresolved issues regarding the statistical approach; and need for several contacts to gain access to a mine for the sampling. The third mine was finally sampled from July 21 to August 14, 1980.

The actual schedule for the study is shown in chart form in Figure 2-3. The distribution of sampling periods by season should be noted. Two occurred during July-August, when emission rates would be expected to be near their maximum. One of these mines was also sampled in December, when fugitive dust rates would normally be relatively low in the Powder River Basin. The fourth sampling period was in October, a season during which potential for dust generation would be near the annual average.

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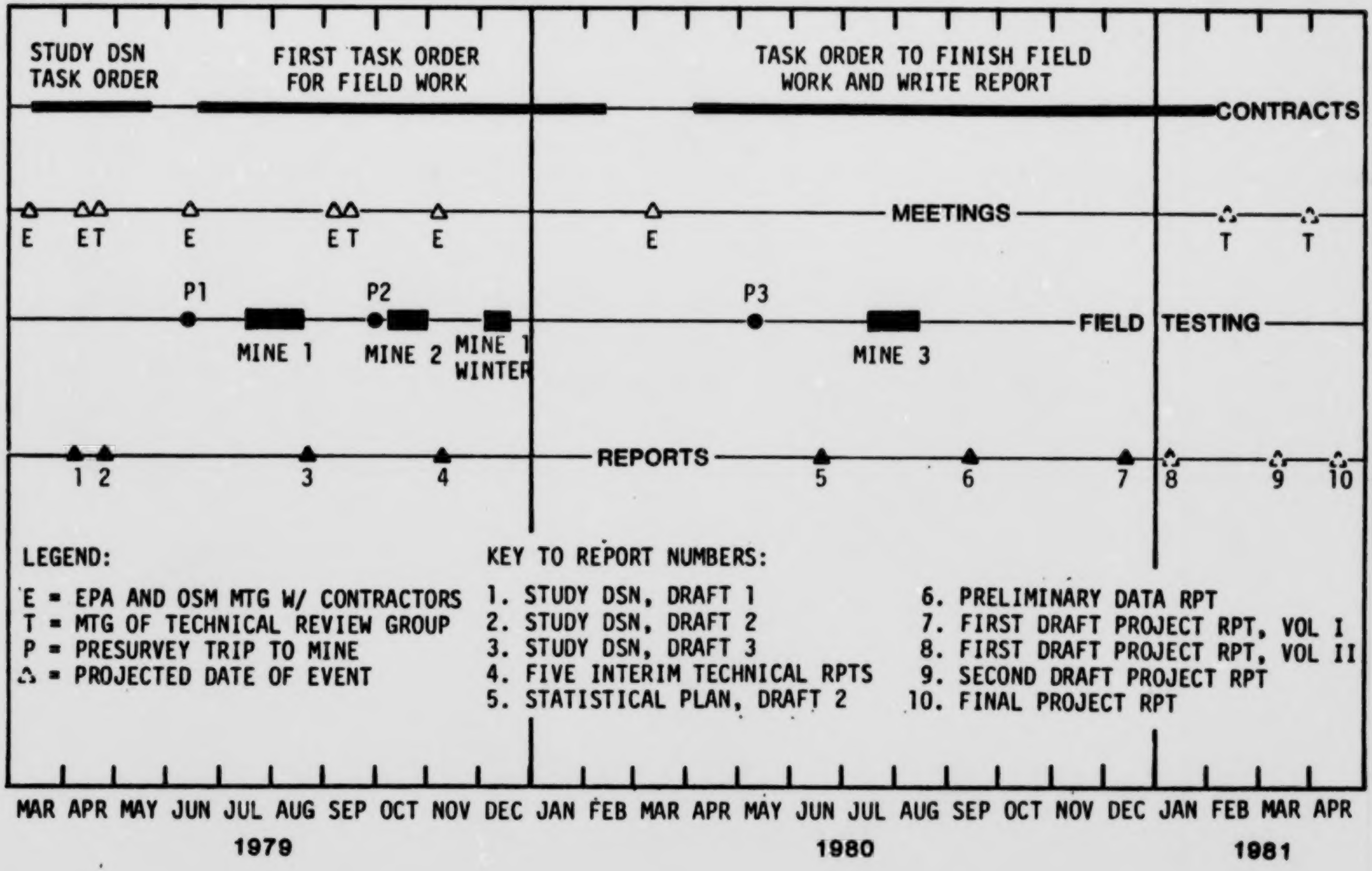

Figure 2-3. Schedule for coal mining emission factor development study.

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SECTION 3

SAMPLING METHODOLOGY

TECHNIQUES AVAILABLE TO SAMPLE FUGITIVE DUST EMISSIONS

Five basic techniques have been used to measure fugitive dust emissions. These are quasi-stack, roof monitor, exposure profiling, upwind-downwind and wind tunnel. Several experimental sampling methods are in developmental stages.

In the quasi-stack method of sampling, the emissions from a well-defined process are captured in a temporary enclosure and vented to a duct or stack of regular cross-sectional area. The emission concentration and the flow rate of the air stream in the duct are measured using standard stack sampling or other conventional methods.

Roof monitor sampling is used to measure fugitive emisssions entering the ambient air from buildings or other enclosure openings. This type of sampling is applicable to roof vents, doors, windows, or numerous other openings located in such fashion that they prevent the installation of temporary enclosures.

The exposure profiling technique employs a single profile tower with multiple sampling heads to perform simultaneous multi-point isokinetic sampling over the plume cross-section. The profiling tower is 4 to 6 meters in height and is located downwind and as close to the source as possible (usually 5 meters). This method uses monitors located directly upwind to determine the background contribution. A modification of this technique employs balloon-suspended samplers.

With the upwind-downwind technique, an array of samplers is set up both upwind and downwind of the source. The source contribution is determined to be the difference between the upwind and downwind concentrations. The resulting contribution is then used in standard dispersion equations to back-calculate the source strength.

The wind tunnel method utilizes a portable wind tunnel with an open-floored test section placed directly over the surface to be tested. Air is drawn through the tunnel at controlled velocities. A proble is located at the end of the test section and the air is drawn thorugh a sampling train.

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Several sampling methods using new sampling equipment or sampling arrays are in various stages of development. These include tracer studies, lidar, acoustic radar, photometers, quartz crystal impactors, etc.

SELECTION OF SAMPLING METHODS

Each of the five basic techniques used to measure fugitive dust emissions has inherent advantages, disadvantages, and limitations to its use.

The quasi-stack method is the most accurate of the airborne fugitive emission sampling techniques because it captures virtually all of the emissions from a given source and conveys them to a measurement location with minimal dilution (Kalika et al. 1976). Its use is restricted to emission sources that can be isolated and are arranged to permit the capture of the emissions. There are no reported uses of this technique for sampling open sources at mines.

The roof monitor method is not as accurate as the quasi-stack method because a significant portion of the emissions escape through other openings and a higher degree of dilution occurs before measurement. This method can be used to measure many indoor sources where emissions are released to the ambient air at low air velocities through large openings. With the exception of the preparation plant and enclosed storage, none of the sources at mines occur within buildings.

The exposure profiling technique is applicable to sources where the ground-based profiler tower can be located vertically across the plume and where the distance from the source to the profiling tower can remain fixed at about 5 meters. This limits application to point sources and line sources. An example of a line source that can be sampled with this technique is haul trucks operating on a haul road. Sources such as draglines cannot be sampled using this technique because the source works in a general area (distance between source and tower cannot be fixed), and because of sampling equipment and personnel safety.

The upwind-downwind method is the least accurate of the methods described because only a small portion of the emssions are captured in the highly diluted transport air stream (Kalika et al. 1976). It is, however, a universally applicable method. It can be used to quantify emissions from a variety of sources where the requirements of exposure profiling cannot be met.

The wind tunnel method has been used to meausre wind erosion of soil surfaces and coal piles (Gillette 1978; Cowherd et al. 1979). It offers the advantages of measurement of wind erosion under controlled wind conditions. The flow field in the tunnel has been shown to adequately

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simulate the properties of ambient winds which entrain particles from erodible surfaces (Gillette 1978).

Experimental sampling methods present at least three problems for coal mine applications. First, none have been used in coal mines to date. Second, they are still in experimental stages, so considerable time would be required for testing and development of standard operating procedures. Third, the per sample costs would be considerably higher than for currently available sampling techniques, thus reducing the number of samples that could be obtained. Therefore, these techniques were not considered applicable methods for this study.

After review of the inherent advantages, disadvantages and limitations of each of the five basic sampling techniques, the basic task was to determine which sampling method was most applicable to the specific sources to be sampled, and whether that method could be adapted to meet the multiple objectives of the study and the practical constraints of sampling in a surface coal mine.

Drilling was the only source which coul be sampled with the quasi-stack method. No roof monitor sampling could be performed because none of the sources to be sampled occurs within a building. It was decided that the primary sampling method of the study would be exposure profiling. The decision was based primarily on the theoretically greater accuracy of the profiling technique as opposed to upwind-downwind sampling and its previous use in similar applications. Where the constraints of exposure profiling could not be met (point sources with too large a cross-sectional area), upwind-downwind would be used. The wind tunnel would be used for wind erosion sampling.

SAMPLING CONFIGURATIONS

Basic Configuration

Exposure Profiling--

Source strength--The exposure profiler consisted of a portable tower, 4 to 6 m in height, supporting an array of sampling heads. Each sampling head was operated as an isokinetic exposure sampler. The air flow stream passed through a settling chamber (trapping particles larger than about 50 um in diameter), and then flowed upward through a standard 8 in. x 10 in. glass fiber filter positioned horizontally. Sampling intakes were pointed into the wind, and the sampling velocity of each intake was adjusted to match the local mean wind speed as determined prior to each test. Throughout each test, wind speed was monitored by recording anemometers at two heights, and the vertical wind speed profile was determined by assuming a logarithmic distribution. This distribution

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has been found to describe surface winds under neutral atmospheric stability, and is a good approximation for other stability classes over the short vertical distances separating the profiler samplers (Cowherd, Axetell, Guenther, and Jutze 1974). Sampling time was adequate to provide sufficient particulate mass (≤ 10 mg) and to average over several units of cyclic fluctuation in the emission rate (e.g., vehicle passes on an unpaved road). A diagram of the profiling tower appears in Figure 3-1.

The devices used in the exposure profiling tests to measure concentrations and/or fluxes of airborne particulate matter are listed in Table 3-1. Note that only the (isokinetic) profiling samplers directly measure particulate exposure (mass per unit intake area) as well as particulate concentration (mass per unit volume). However, in the case of the other sampling devices, exposure may be calculated as the product of concentration, mean wind speed at the height of the sampler intake, and sampling time.

Two deployments of sampling equipment were used in this study: the basic deployment described in Table 3-2 and the special deployment shown in Table 3-3 for the comparability study.

Particle size-- Two Sierra dichotomous samplers, a standard hi-vol, and a Sierra cascade impactor were used to measure particle sizes downwind. The dichotomous samplers collected fine and coarse fractions with upper cut points (50 percent efficiency) of 2.5 µm and approximately 15 um. (Adjustments for wind speed sensitivity of the 15 µm cut point are discussed in Section 5; limitations of this sampling technique are described in Section 12.

The high-volume parallel-slot cascade impactor with a 20 cfm flow controller was equipped with a Sierra cyclone preseparator to remove coarse particles that otherwise would tend to bounce off the glass fiber impaction substrates. The bounce-through of coarse particles produces an excess of catch on the backup filter. This results in a positive bias in the measurement of fine particles (see Page 6-3). The cyclone sampling intake was directed into the wind and the sampling velocity adjusted to mean wind speed by fitting the intake with a nozzle of appropriate size, resulting in isokinetic sampling for wind speeds ranging from 5 to 15 mph.

Deposition-- Particle deposition was measured by placing dustfall buckets along a line downwind of the source at distances of 5 m, 20 m, and 50 m from the source. Greater distances would have been desirable for establishing the deposition curve, but measureable weights of dustfall could not be obtained beyond about 50 m during th 1-hour test periods. Dustfall buckets were collocated at each distance. The bucket openings were located 0.75 m above ground to avoid the impact of saltating particles generated by wind erosion downwind of the source.

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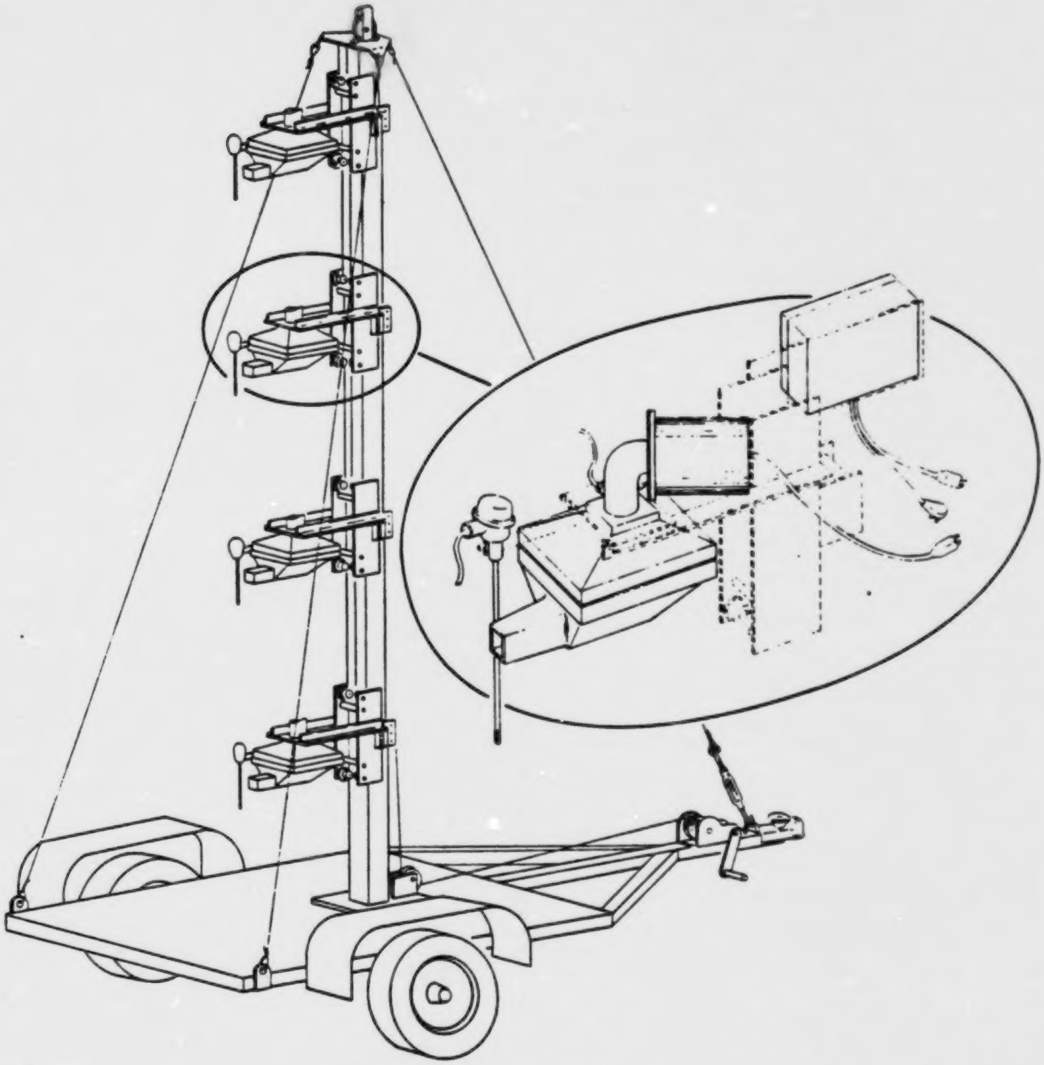

Figure 3-1. Exposure profiler.

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TABLE 3-1. SAMPLING DEVICES FOR ATMOSPHERIC PARTICULATE MATTER--EXPOSURE PROFILING

Particulate matter category[a]	Air sampling device			
	Type	Quantity measured	Operating flow rate	Flow Calibrator
TP	Exposure profiler head	Exposure and concentration	Variable (10-50 SCFM) to achieve isokinetic sampling	Anemometer calibrator
	Cyclone with interchangeable probe tips and backup filter	Exposure and concentration	20 ACFM	Orifice calbrator
TSP	Standard hi-vol	Concentration	40-60 ACFM	Orifice calibrator
IP	Dichotomous sampler	Concentration	0.59 ACFM	Dry test meter
FP	Dichotomous sampler	Concentration	0.59 ACFM	Dry test meter

[a] TP = Total particulate = All particulate matter in plume
TSP = Total suspended particulate = Particulate matter in size range collected by hi-vol, estimated to be less than about 30 μm diameter
IP = Inhalable particulate = Particulate less than 15 μm diameter
FP = Fine particulate = Particulate less than 2.5 μm diameter

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TABLE 3-2. BASIC EQUIPMENT DEPLOYMENT FOR EXPOSURE PROFILING

Location	Distance from Source (m)	Equipment	Intake Height (m)[a]
Upwind	5	1 Dichotomous sampler	2.5
		1 Standard hi-vol	2.5
		2 Dustfall buckets	0.75
		1 Continuous wind monitor	4.0
Downwind	5-10	1 MRI exposure profiler with 4 sampling heads	1.5 (1.0) 3.0 (2.0) 4.5 (3.0) 6.0 (4.0)
		1 Standard hi-vol	2.5 (2.0)
		1 Hi-vol with cascade impactor	2.5 (2.0)
		2 Dichotomous samplers	1.5 4.5 (3.0)
		2 Dustfall buckets	0.75
		2 Warm wire anemometers	1.5 (1.0) 4.5 (3.0)
Downwind	20	2 Dustfall buckets	0.75
Downwind	50	2 Dustfall buckets	0.75

[a] Alternative heights for sources generating lower plume heights are given in parentheses.

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TABLE 3-3. SPECIAL EQUIPMENT DEPLOYMENT FOR EXPOSURE PROFILING--COMPARABILITY TESTS

Location	Distance from Source (m)	Equipment	Intake Height (m)
Upwind	5 to 10	1 Standard hi-vol	1.25
		1 Standard hi-vol	2.5
		2 Dustfall buckets	0.75
		1 Continuous wind monitor	4.0
Downwind	5	1 MRI exposure profiler with 4 sampling heads	1.5
			3.0
			4.5
			6.0
		1 Standard hi-vol	2.5
		2 Hi-vols with cascade impactors	1.5
		4 Dichotomous samplers	1.5
			3.0
			4.5
			6.0
		2 Dustfall buckets	0.75
		2 Warm wire anemometers	1.5
			4.5
Downwind	20	1 Hi-vol with cascade impactor	2.5
		2 Dustfall buckets	0.75
Downwind	50	2 Dustfall buckets	0.75

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Exposure Profiling Modification for Sampling Blasts--

Source strength-- The exposure profiler concept was modified for sampling blasts. The large horizontal and vertical dimensions of the plumes necessitated a suspended array of samplers as well as ground-based samplers in order to sampler over the plume cross-section in two dimensions. Five 47 mm PVC filter heads and sampling orifices were attached to a line suspended from a tethered balloon. The samplers were located at five heights with the highest at 30.5 m (2.5, 7.6, 15.2, 22.9, and 30.5 m). Each sampler was attached to a wind vane so that the orifices would face directly into the wind. The samplers were connected to a ground based pump with flexible tubing. The pump maintained an isokinetic flow rate for a wind speed of 5 mph. In order to avoid equipment damage from the blast debris and to obtain a representative sample of the plume, the balloon-suspended samplers were located about 100 m downwind of the blast area. This distance varied depending on the size of the blast and physical constraints. The distance was measured with a tape measure. The balloon-supported samplers were supplemented with five hi-vol/dichot pairs located on an arc, at the same distance as the balloon from the edge of the blast area. These were spaced 20 m apart on the arc.

Particle size-- The five ground-based dichotomous samplers provided the basic particle size information.

Deposition--There was no measurement of deposition with this sampling method. Dustfall samples would have been biased by falling debris from the blast.

Upwind-Downwind--

Source strength-- The total upwind-downwind array used for sampling point sources included 15 samplers, of which 10 were hi-vols and 5 were dichotomous samplers. The arrangement is shown schematically in Figure 3-2. The downwind distances of the samplers from point sources were nominally 30 m, 60 m, 100 m, and 200 m. Frequently, distances in the array had to be modified because of physical obstructions (e.g., highwall) or potential interfering sources. A tape measure was used to measure source-to-sampler distances. The upwind samplers were placed 30 to 100 m upwind, depending on accessibility. The hi-vol and dichotomous samplers were mounted on tripod stands at a height of 2.5 m. This was the highest manageable height for this type of rapid-mount stand.

This array was modified slightly with sampling line sources. The array consisted of two hi-vol/dichot pairs at 5 m, 20 m, and 50 m with 2 hi-vols at 100 m. The two rows of samplers were normally separated by 20 m.

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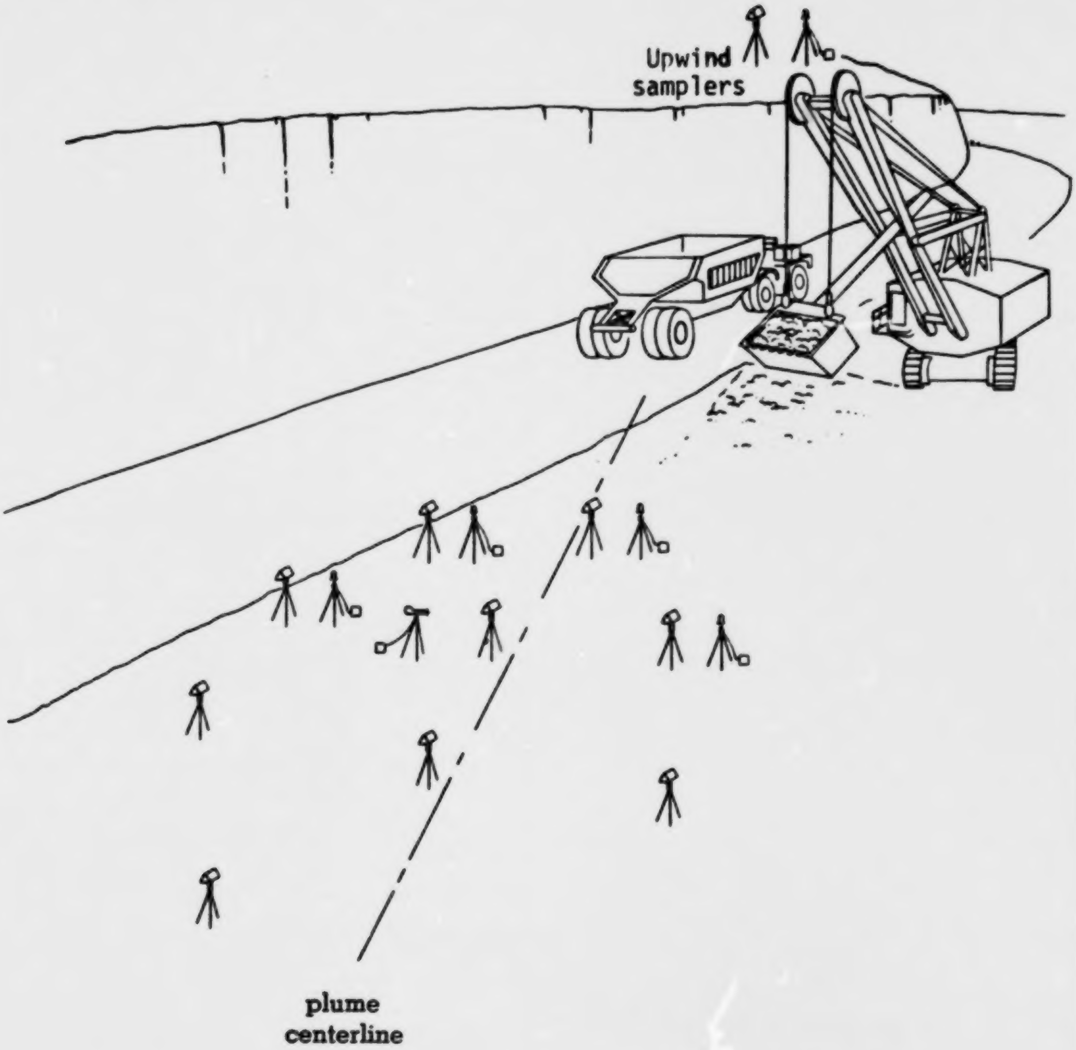
Upwind samplers
plume centerline

Figure 3-2. Upwind-downwind sampling array.

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Particle size-- In addition to the dichotomous samplers located upwind of the source and at 30 m and 60 m distances downwind of the source, millipore filters were exposed for shorter time period during the sampling at different downwind distances. These filters were to be subjected to microscopic examination for sizing, but most of this work was suspended because of poor agreement of microscopy with aerodynamic sizing methods in the comparability study.

Deposition-- The upwind-downwind method allows indirect measurement of deposition through calculation of apparent emission rates at different downwind distances. The reduction in apparent emission rates as a function of distance is attributed to deposition. At distances beyond about 100 m, deposition rates detemined by this method would probably be too small to be detected separate from plume dispersion.

Wind Tunnel--

Source strength--For the measurement of dust emissions generated by wind erosion of exposed areas and storage piles, a portable wind tunnel was used. The tunnel consisted of an inlet section, a test section, and an outlet diffuser. As a modification to previous wind tunnel designs, the working section had a 1 foot by 1 foot cross section. This enlargement was made so that the tunnel could be used with rougher surfaces. The open-floored test section of the tunnel was placed directly on the surface to be tested (1 ft x 8 ft), and the tunnel air flow was adjusted to predetermined values that corresponded to the means of the upper NOAA wind speed ranges. Tunnel wind speed was measured by a pitot tube at the downstream end of the test section. Tunnel wind speeds were related to wind speed at the standard 10 m height by means of a logrithmic profile.

An airtight seal was maintained along the sides of the tunnel by rubber flaps attached to the bottom edges of the tunnel sides. These were covered with material from areas adjacent to the test surface to eliminate air infiltration.

To reduce the dust levels in the tunnel air intake stream, testing was conducted only when ambient winds were well below the threshold velocity for erosion of the exposed material. A portable high-volume sampler with an open-faced filter (roof structure removed) was operated on top of the inlet section to measure background dust levels. The filter was vertically oriented parallel to the tunnel inlet face.

An emission sampling module was used with the pull-through wind tunnel in measuring particualte emissions generated by wind erosion. As shown in Figure 3-3, the sampling module was located between the tunnel outlet hose and the fan inlet. The sampling train, which was operated at 15-25 cfm,

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consisted of a tapered probe, cyclone precollector, parallel-slot cascade impactor, backup filter, and high-volume motor. Interchangeable probe tips were sized for isokinetic sampling over the desired tunnel wind speed range. The emission sampling train and the portable hi-vol were calibrated in the field prior to testing.

Particle size--The size distribution for 30 µm and smaller particles was generated from the cascade impactor used as the total particulate sampler. The procedure for correction of the size data to account for particle bounce-through is described in Section 5.

Deposition--No method of measuring the deposition rate of particles suspended by wind erosion in the test section could be incorporated into the design of the wind tunnel.

Quasi-Stack--

Source strength--An enclosure was fabricated consisting of an adjustable metal frame covered with plastic. The frame was 6 feet long with maximum openings at the ends of 5 x 6 feet. Due to problems with the plastic during high winds, the original enclosure was replaced with a wood enclosure with openings 4 x 6 feet, as shown in Figure 3-4. For each test, the enclosure was placed downwind of the drill base. The outlet area was divided into four rectangles of area, and the wind velocity was measured at the center of each rectangle with a hot wire anemometer to define the wind profile inside the frame.

Four exposure profiler samplers with flow controllers were used to sample the plume. Using the wind profile data, the sampler flow rates were adjusted to 2 to 3 minute intervals to near-isokinetic conditions.

Particle size--The only particle size measurements made with this sampling method was the split between the filter catch and settling chamber catch in the profiler heads.

Deposition--There was no direct measurement of deposition with this sampling method.

Sampling Configuration by Source

The basic sampling configurations were adapted to each source to be tested. Sampling configurations used for each source are indicated in Table 3-4 and described below.

Overburden Drilling--

This activity was sampled using the quasi-stack configuration.

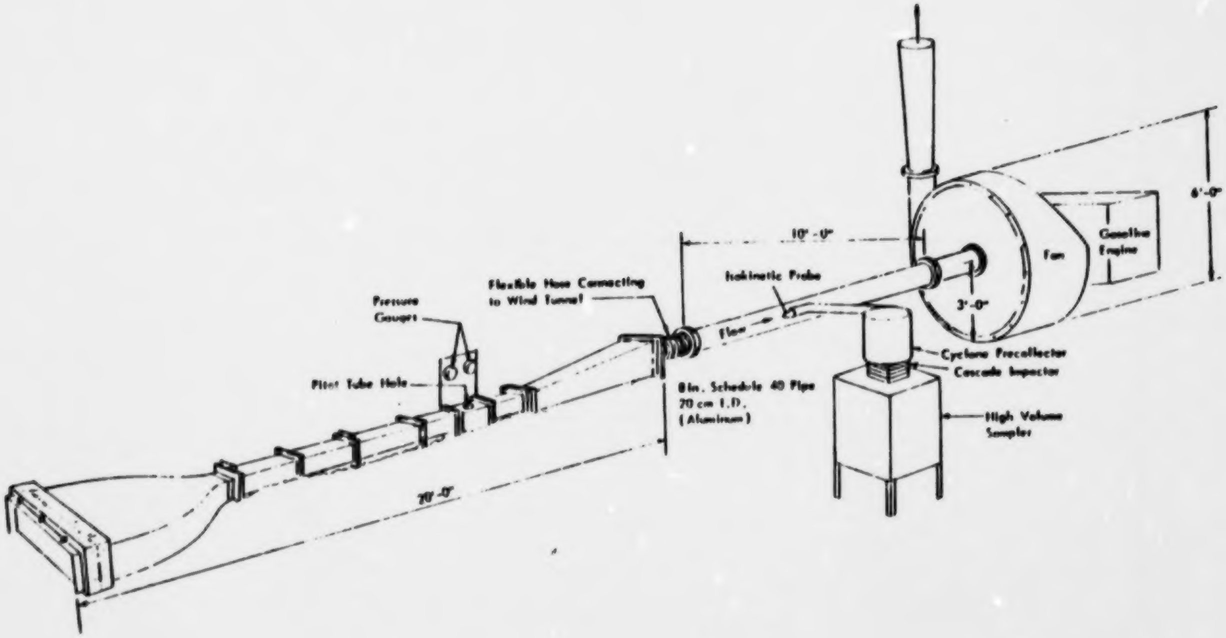
6'-0"
Gasoline Engine
Fan
3'-0"
10'-0"
Isokinetic Probe
Flow
Cyclone Precollector
Cascade Impactor
High Volume Sampler
Flexible Hose Connecting to Wind Tunnel
8 in. Schedule 40 Pipe
20 cm I.D.
(Aluminum)
Pressure Gauges
Pitot Tube Hole
20'-0"

Figure 3-3. Wind tunnel.

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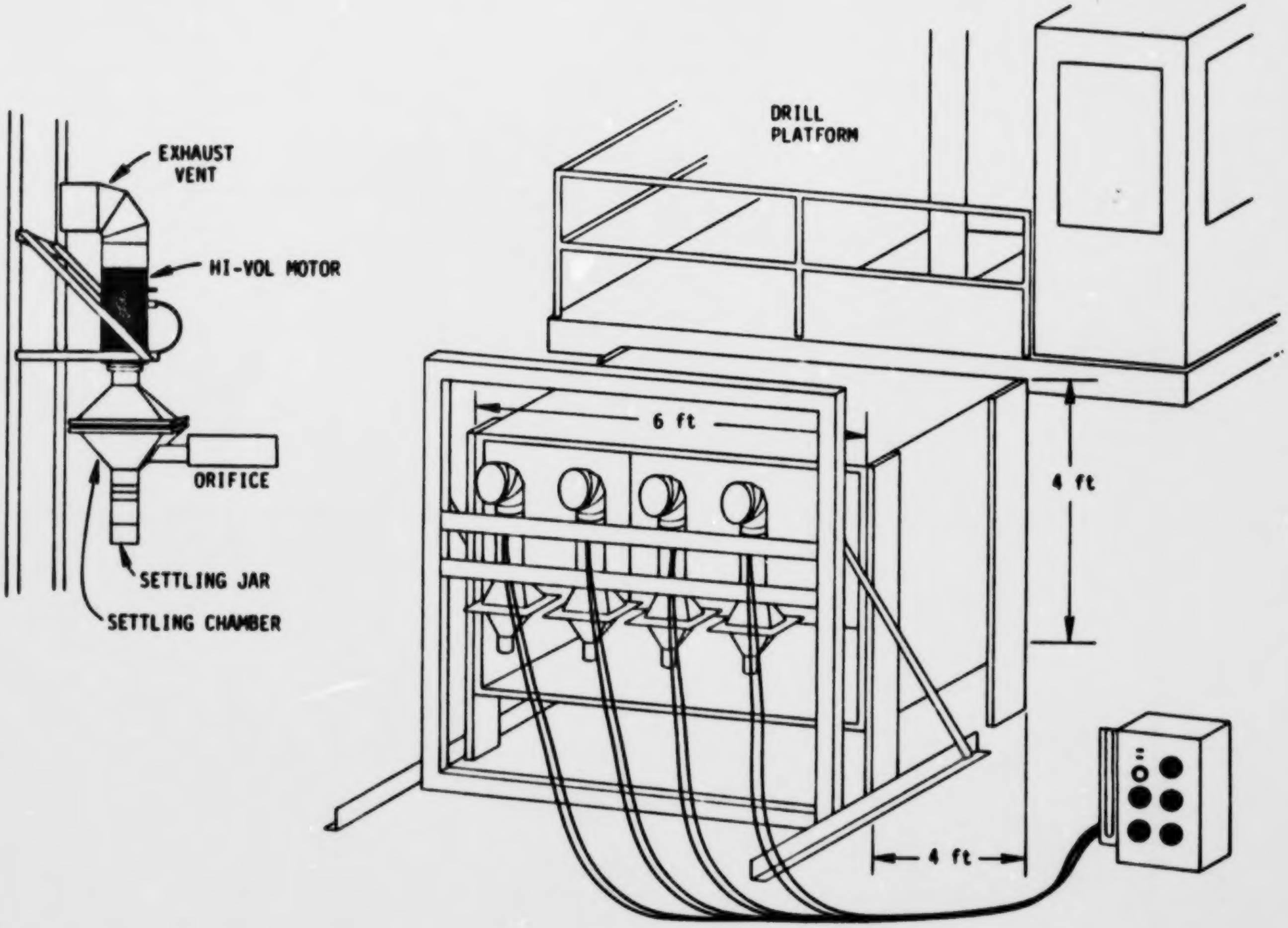
EXHAUST VENT
HI-VOL MOTOR
ORIFICE
SETTLING JAR
SETTLING CHAMBER
DRILL PLATFORM
6 ft
4 ft
4 ft

Figure 3-4. Quasi-stack sampling--temporary enclosure for drill sampling.

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TABLE 3-4. SAMPLING CONFIGURATIONS FOR SIGNIFICANT SOURCES

Source	Point, line, or area[a]	Sampling configuration
Drilling (overburden)	Point	Quasi-stack
Blasting (coal and overburden)	Area	Exposure profiling (modification)
Coal loading (shovel/truck and front-end loader)	Point or area	Upwind/downwind
Dozer (coal and overburden)	Line or point	Upwind/downwind
Dragline	Point or area	Upwind/downwind
Haul truck	Line	Exposure profiling
Light- and medium-duty vehicles	Line	Exposure profiling
Scraper	Line	Exposure profiling
Grader	Line	Exposure profiling
Wind erosion of exposed areas	Area	Wind tunnel
Wind erosion of storage piles	Area	Wind tunnel

[a] Several of these sources could be operated as a line, point, or area source. Where possible, the predominant method of operation was used. In other cases, sampling requirements dictated the type of operation.

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Blasting--

The plume from a blast is particularly difficult to sample because of the vertical and horizontal dimensions of the plume and the inability to place sampling equipment near the blast. Further, the plume is suspected to be non-Gaussian because of the way in which the plume is initially formed. Therefore, upwind-downwind sampling is not appropriate. To sample blasts, a modification of the exposure profiling technique was developed. This modification was discussed previously. A typical sampling array is shown in Figure 3-5. The same sampling procedure was used for overburden blasts and coal blasts.

Coal Loading with Shovels or Front-End Loaders--

The exposure profiler could not be used for this source because of movement of the plume origin. Therefore, the upwind-downwind configuration for point sources was used. There are many points at which dust is emitted during truck loading--pulling the truck into position, scooping the material to be loaded, lifting and swinging the bucket, dropping the load, driving the truck away, and cleanup of the area by dozers or front-end loaders. Dropping of the load into the truck was generally the largest emission point so its emissions were used as the plume centerline for the sampling array, with the array spread wide enough to collect emissions from all the dust-producing points. Bucket size was recorded for each test, as well as the number of bucket drops.

Wind conditions and the width of the pit dictated the juxtaposition of the source and sampler array. When the winds channeled through the pit and the pit was wide enough to set up the sampling equipment out of the way of haul trucks, the samplers were set up downwind and in the pit. When winds were perpendicular to the pit, the sampling array was set up on a bench if the bench was not more than 5 to 7 meters high. With this configuration, the top of the haul truck was about even with the height of the bench; emissions from the shovel drop point could be very effectively sampled in this manner. Two coal loading sampling arrays are shown in Figure 3-6.

Dozers--

Dozers are difficult to test because they may operate either as a line source or in a general area as large as several acres over a 1-hour test period. When a dozer operated as a line source, the upwind-downwind configuration for a line source was used. The samplers were located with the assumed plume centerline perpendicular to the line of travel for the dozer. The number of times the dozer passed the samplers was recorded for each test. Since dozers could not always be found operating as a line source, captive dozers were sometimes used so that test conditions could be more accurately controlled. To sample dozers working in an area, the upwind-downwind point source configuration was used. The location and size of the area was recorded along with dozer movements.

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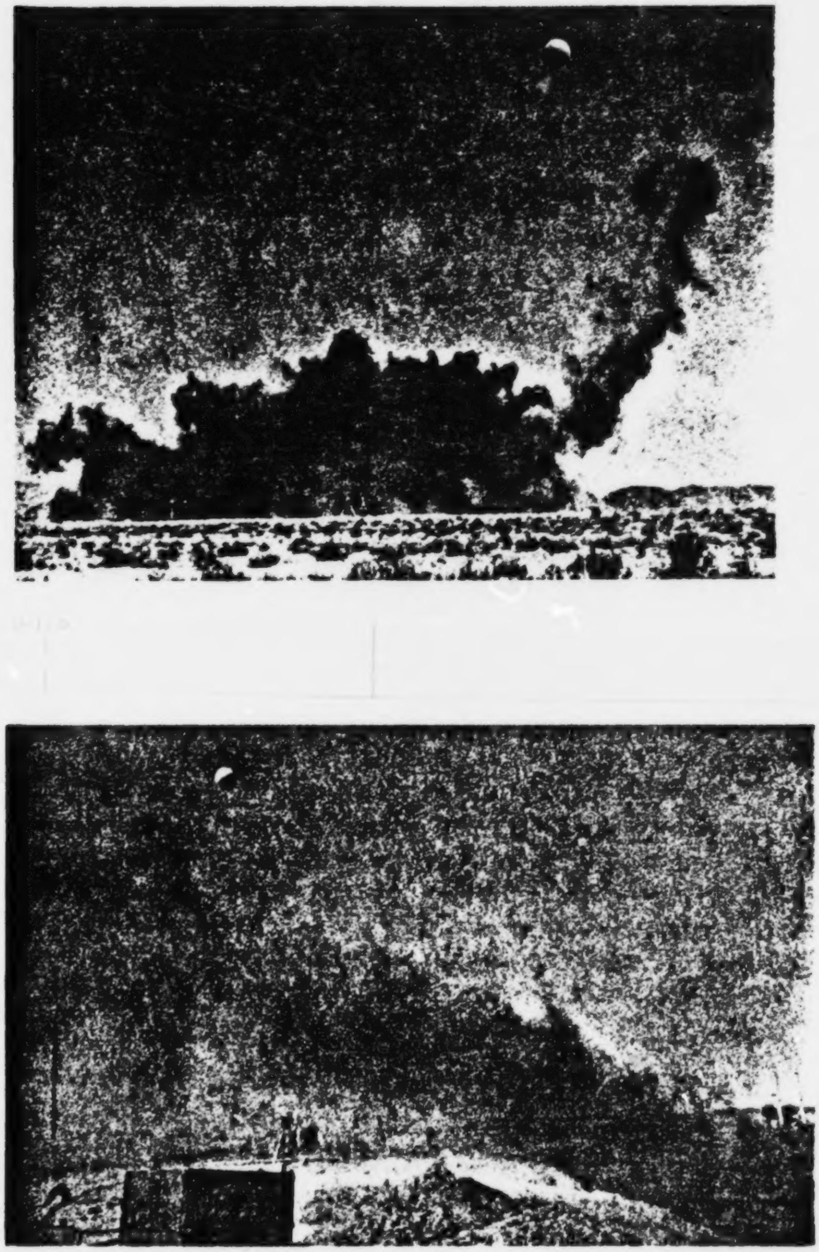

Figure 3-5. Blast sampling with modified exposure profiling configuration.

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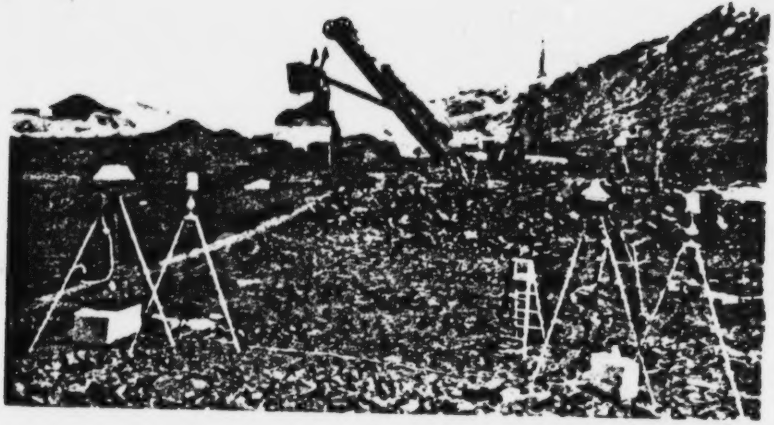
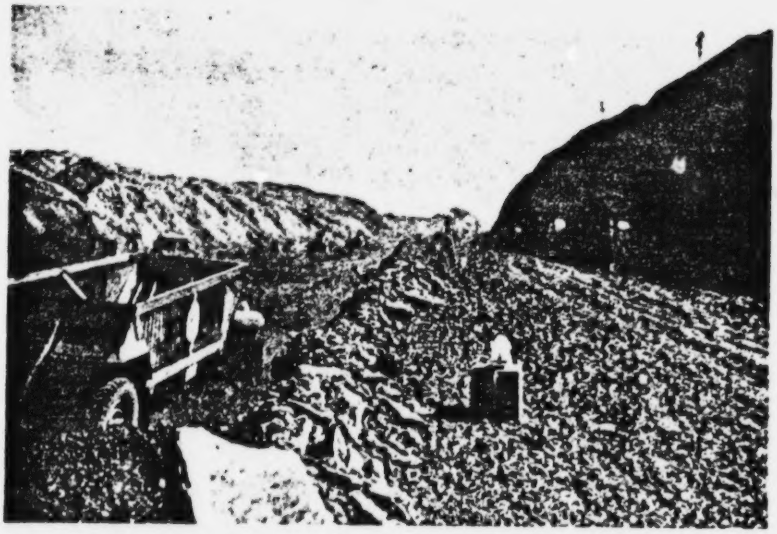


Sampling array in the pit



Sampling array on a bench

Figure 3-6. Coal loading with upwind-downwind configuration.

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Dragline--

Sampling of this source was performed with the upwind-downwind configuration because of the large initial dimensions of the plume and because of the impossibility of placing samplers near the plume origin. There are three emission points--pickup of the overburden material, material lost from the bucket during the swing, and overburden drop. It was not always possible to position samplers so they were downwind of all three points. Therefore, sketches were made of each setup and field notes were recorded as to which points were included in the test. The number of drops, average drop distance, and size of the dragline bucket were also recorded.

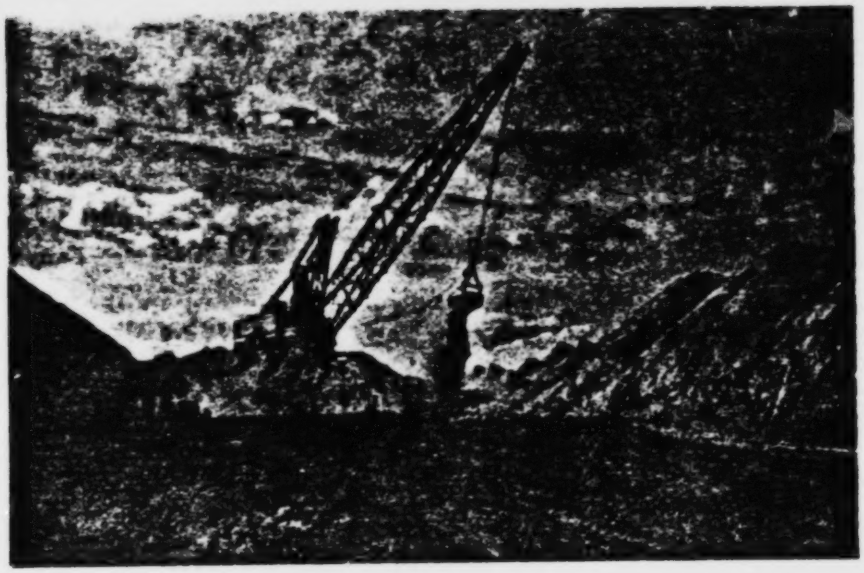
Location of the samplers relative to the dragline bucket was determined by wind orientation, size of the pit (width and length) and pit accessibility. When winds were parallel to the pit, the array was set up in the pit if there was sufficient space and the plumes from all three emission points passing over the samplers. When winds were perpendicular to the pit, draglines were only sampled if samplers could be placed on a bench downwind at approximately the same height as the spoils pile where the overburden was being dropped. Figure 3-7 shows the two typical dragline sampling configurations.

Haul Trucks--

Most sampling periods for haul trucks at the first mine were performed as part of the comparability study (see Section 6), employing both exposure profiling and upwind-downwind configurations. Haul trucks were used to perform the comparative study because they are a uniformly-emitting line source and because haul road traffic is the largest particualte source in most mines. At subsequent mines, exposure profiling was used to sample this source. For each test, the wind was approximately perpendicular to the road, the air intakes of the samplers were pointed directly into the wind, and the samplers extended to a height of 6 m to capture the vertical extent of the plume. In a few cases, more than <U10 of the plume mass extended above the top sampler because of a combination of light winds, unstable atmospheric conditions, and large vehicles. Consistent travel speed and diversion of watering trucks was requested during each sampling period. A haul truck sampling array is shown in Figure 3-8.

Light- and Medium-Duty Vehicles--

The sampling methodology for this category of vehicles was nearly identical to the haul truck procedures. The only exceptions were that: (1) a 4 m sampler height was adequate to sample the plume from the smaller vehicles and (2) pickup trucks belonging to the contractor were used for better control of vehicle speed and weight. In most cases, access roads



Sampling array in the pit

Sampling array at about the same height as the spoils pile

Figure 3-7. Dragline sampling with upwind-downwind configuration

specifically for lighter vehicles were used to testing. However, some sampling for light- and medium-duty vehicles was done on haul roads. Samples of the road surfaces were taken so that differences due to road properties could be evaluated (a full discussion of source characterization is included in the next subsection). A light- and medium-duty vehicle sampling array is shown in previously cited Figure 3-8.

Scraper--

This source was sampled by the exposure profiling method. Scrapers were sampled while traveling on a temporary road so that the emissions could be tested as a line source. Neither the loading nor the emptying operations were sampled, since both had been estimated to have insignificant emissions compared to scraper travel. The profiler was extended to 6 m to sample the vertical extent of the plume. In order to secure a suitable setup in a location with interference from other sources, it was often necessary to use captive equipment. A typical sampling array for scrapers is shown in Figure 3-9.

Graders--

Exposure profiling was used to sample graders. Graders operate in a fairly constant manner; only the speed and travel surface (on road/off road) vary over a time. It was assumed that the travel surface could be considered as a correction factor rather than requiring two separate emission factors. As with dozers, captive equipment was sometimes necessary to sample this source because graders did not normally drive past the same location repetitively. Even if there were regarding a short stretch of road, they would be at a different location on the road cross section with each pass, making it difficult to reposition the profiler. Therefore, captive equipment allowed better control of test variables.

Wind Erosion of Exposed Areas and Storage Piles--

The wind tunnel was used to sample these two sources. In measuring emissions with the portable wind tunnel, it was necessary to place the tunnel on a flat, nearly horizontal section of surface. Care was taken not to disturb the natural crust on the surface, with the exception of removing a few large clumps that prevented the tunnel test section from making an airtight seal with the surface.

The threshold velocity for wind erosion and emission rates at several predetermined wind speeds above the threshold were measured on each test surface. Wind erosion of exposed surfaces had been shown to decay in time for velocities well above the threshold value for the exposed surface. Therefore, some tests of a given surface were performed sequentially to trace the decay of the erosion rate over time at high test velocities. A typical wind tunnel sampling configuration is shown in Figure 3-10.

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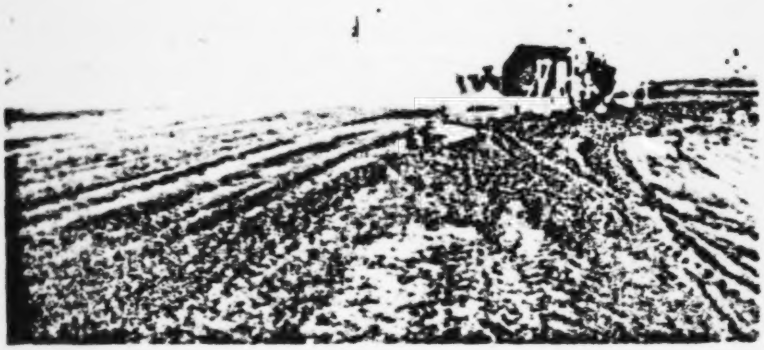
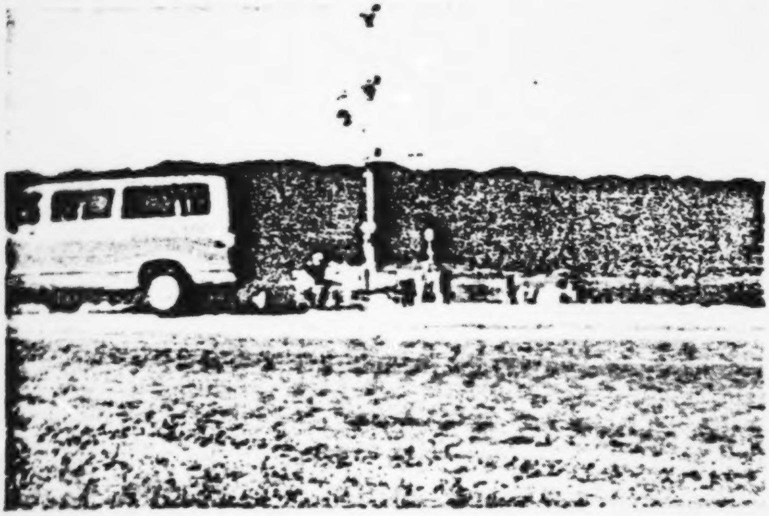


Haul truck travel



Light- and medium-duty truck

Figure 3-8. Haul road sampling with exposure profiling configuration.

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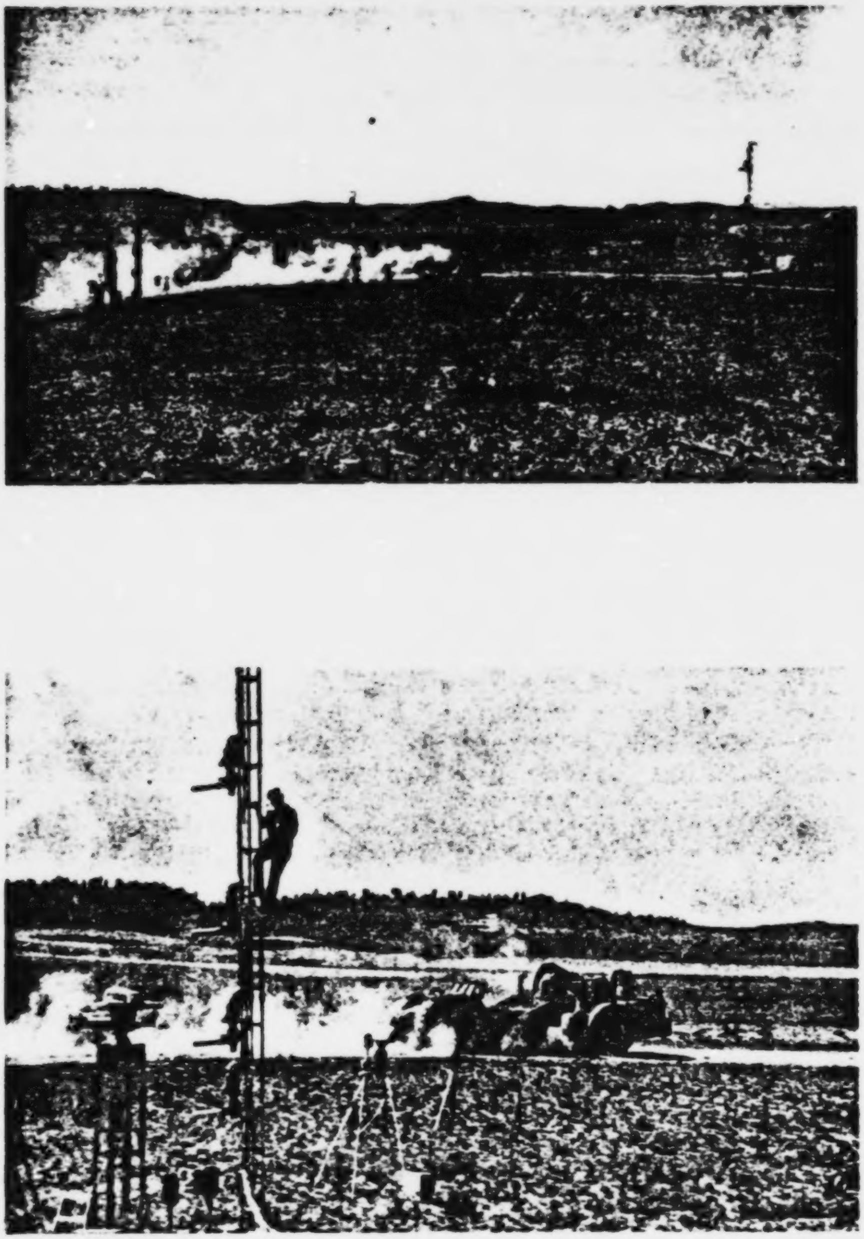

Figure 3-9. Scraper sampling with exposure profiling configuration.

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Changes Made in Response to Comments

Tha basic sampling designs presented above represents the combined efforts of the two contractors as well as comments received from the technical review group. Specific changes made in response to technical review group comments are summarized below.

1. Dichotomous samplers were added to the exposure profiling sampling method. They were placed at four heights corresponding to the isokinetic sampling heights during the comparability study, and at two heights for the remainder of the tests. With this arrangement, dichotomous samplers replaced the cascade impactor as the primary particle size sampler in exposure profiling.
2. A fourth row of downwind sampler was added to the upwind-downwind array. Two hi-vols were placed at 200 m from the source to aid in the measurement of deposition.
3. The quasi-stack sampling method was adopted for sampling overburden drilling and an enclosure was designed and fabricated.
4. The modification of the exposure profiling method to sample blasts was devised.
5. Provisions were made to sample scrapers, and other sources as required, as captive equipment in locations not subject to other dust interferences.

SOURCE CHARACTERIZATION PROCEDURES

In order to determine the parameters that affect dust generation from an individual source, the suspected parameters must be measured at the time of the emission test. These parameters fall into three categories: properties of the materials being disturbed by wind or machinery, operating parameters of the mining equipment involved, and meteorological conditions. Table 3-5 lists the potential parameters by source that were quantified during the study.

Representative samples of materials (topsoil, overburden, coal, or road surface) were obtained at each test location. Unpaved and paved roads were sampled by removing loose material of road surface extending across the travel portion. Loose aggregate materials being transferred were sampled with a shovel to a depth exceeding the size of the largest aggregate pieces. Erodible surfaces were sampled to a depth of about 1 centimeter. The samples were analyzed to determine moisture and silt content.

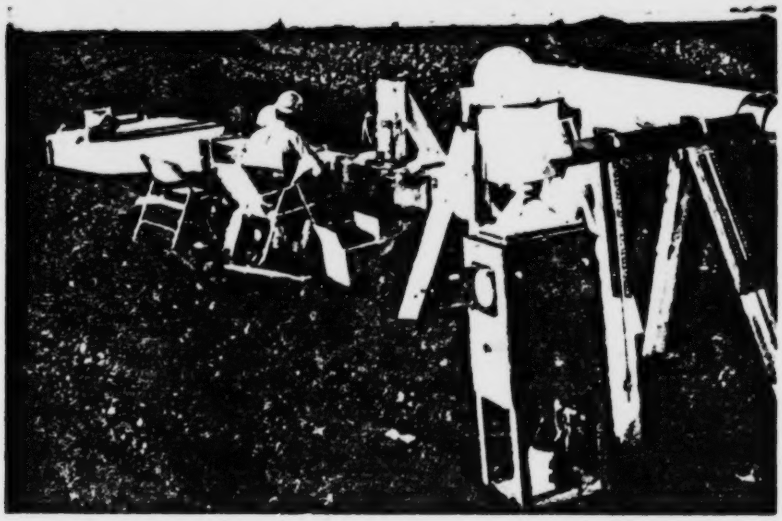

Figure 3-10. Wind erosion sampling with wind tunnel.

Mining equipment travel speeds were measured by radar gun or with a stop watch over a known travel distance. Equipment specifications and traveling weights were obtained from mine personnel. For several sources, it was necessary to count vehicle passes, bucket drops, etc. These counts were usually recorded by two people during the test to ensure the accuracy of the results. Frequent photographs were taken during each test to establish the sampling layout (to supplement the ground-measured distances), source activity patterns, and plume characteristics.

Micro-meteorological conditions were recorded for each test. Most of these data were used in the calculation of concentrations or emission rates rather than as potential correction factors for the emission factor equations. During the test, a recording wind instrument measured wind direction and wind speed at the sampling site. A pyranograph was used to measure solar intensity. Humidity was determined with a sling psychrometer. A barometer was used to record atmospheric pressure. The percent of cloud cover was visually estimated.

In addition to monitoring micro-meteorological conditions, a fixed monitoring station at the mine monitored parameters affecting the entire area. Data were recorded on temperature, humidity, wind speed and direction, and precipitation.

ADJUSTMENTS MADE DURING SAMPLING

The sampling configurations detailed in this section were the result of a careful study design process completed prior to actual field sampling. Actual field conditions forced changed to elements of the study design.

A modification to the upwind-downwind sampling array was required. Whereas the study design called for two hi-vols at 200 m downwind of the source, this setup could not be adapted to field conditions. Three major reasons for the deviation from the study designs were: (a) the difficulty of locating the samplers where they were not subjected to other dust interferences; (b) the difficulty of extending power to the samplers; and (c) in many sampling locations, there was not 200 m of accessible ground downwind of the source. Therefore, only 1 hi-vol was routinely placed at the 200 m distance and in some cases no sampler was located at that distance.

Four modifications were made to the exposure profiling sampling array. First, it was impractical to mount dichotomous samplers at all four heights on the profiling tower as called for in the original study design. Dichotomous samplers were placed at two heights. Second, the study design called for an exposure profiling test to be terminated if the standard deviation of the wind direction exceeded 22.5° during test period. Because unstable atmospheric conditions were encountered at Mine 1 during the summer season,

TABLE 3-5. SOURCE CHARACTERIZATION PARAMETERS MONITORED DURING TESTING

Source	Parameter[a]	Quantification technique
All tests[a]	Wind speed and direction	Anemometer
	Temperature	Thermometer
	Solar intensity	Pyranograph
	Humidity	Sling psychrometer
	Atmospheric pressure	Barometer
	Percent cloud cover	Visual estimate
Overburden drilling	Silt content	Dry sieving
	Moisture content	Oven drying
	Depth of hole	Drill operator
Blasting	Number of holes	Visual count
	Size of blast area	Measurement
	Moisture content	From mining company
Coal loading	Silt content	Dry sieving
	Moisture content	Oven drying
	Bucket capacity	Equipment specifications
	Equipment operation	Record variations
Dozer	Silt content	Dry sieving
	Moisture content	Oven drying
	Speed	Time/distance
	Blade size	Equipment specifications
Dragline	Silt content	Dry sieving
	Moisture content	Oven drying
	Bucket capacity	Equipment specifications
	Drop distance	Visual estimate
Haul truck	Surface silt content	Dry sieving
	Vehicle speed	Radar gun
	Vehicle weight	Truck scale
	Surface loading	Mass/area of collected road sample
	Surface moisture content	Oven drying
	Number of wheels	Visual observation
Light- and medium-duty vehicles	Same parameters and quantification techniques as for haul trucks	

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TABLE 3-5 (continued).

Source	Parameter[a]	Quantification technique
Scraper	Same parameters and quantification techniques as for haul trucks	
Grader	Same parameters and quantification techniques as for haul trucks	
Wind erosion of exposed areas	Surface erodibility	Dry sieving
	Surface silt content	Dry sieving, before and after test
	Surface moisture content	Oven drying, before and after test
	Surface roughness height	Measurement
Wind erosion of storage piles	Same parameters and quantification techniques as for wind erosion of exposed areas	

[a] Most of the meteorological parameters monitored during all tests are needed to estimate emission rates, and are not considered to be potential correction parameters in the emission factor equations.

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it was necessary to relax this restriction. However, this change had no effect on the direction-insenstive dichotomous sampler which served as the primary sizing device. At the third mine, a second cascade impactor and hi-vol were added alongside the profiler at the height of the third profiling head. This was to provide backup data on particle size distribution in the upper portion of the plume and on the TSP concentration profile. Finally, greased substrates were used with the cascade impactors at the third mine to test whether particle bounce-through observed at the first two mines would be diminished.

A modification was required to the balloon sampling array. The study design specified that the five ground-based sampler pairs be located 10 m apart and that the balloon samplers be located on the blast plume centerline. This was found to be impractical under field conditions. The location of the plume centerline was very dependent on the exact wind direction at the time of the blast. Because the balloon sampling array required at least one hour to set up, it was impossible to anticipate the exact wind direction one hour hence. Therefore, the ground-based samplers were placed 20 to 30 m apart when the wind was variable so that some of the samplers were in the plume. The balloon sometimes could not be moved to the plume centerline quickly enough after the blast. Rapid sequence photography was used during the test to assist in determining the plume centerline; the emission factor calculation procedure was adjusted accordingly.

ERROR ANALYSES FOR SAMPLING METHODS

Separate error analyses were prepared for the exposure profiling and upwind-downwind sampling methods. These analysis were documented in interim technical reports and will be summarized here (Midwest Research Institute 1979; PEDCo Environmental 1979).

A summary of potential errors (1σ) in the exposure profiling method initially estimated by MRI is shown in Table 3-6. Potential errors fall in the categories of sample collection, laboratory analysis, and emission factor calculation. For particles less than 15 μm, the error in the technique was estimated by MRI to range from -14 percent to +8 percent. Subsequent field experience on this project indicated that actual error was 30 to 35 percent in that size range and higher for the less than 30 μm (suspended particulate) size range.

Potential errors initially estimated by PEDCo for the upwind-downwind sampling method are summarized in Table 3-7. A delineation was made between errors associated with line sources and point/area sources. The estimated errors were ±30.5 percent and ±50.1 percent, respectively.

SUMMARY OF TESTS PERFORMED

Sampling performed is shown in Table 3-8. The number of samples are shown by source and mine. A total of 265 tests were completed.

TABLE 3-6. SUMMARY OF POTENTIAL ERRORS IN THE EXPOSURE PROFILING METHOD

Source of error	Error type	Action to minimize error	Estimated error
Sample collection			
1. Instrument error	Random	Planned maintenance, periodic calibration and frequent flow checks	5%[a]
2. Anisokinetic sampling			
a. Wind direction fluctuation	Systematic	$\sigma_\theta < 22.5°$	<10%
b. Non-zero angle of intake to wind	Systematic	$\theta < 30°$	<10%
c. Sampling rate does not match wind speed	Systematic	0.8 < IFR <1.2	<5%
3. Improper filter loading	Systematic	Decrease or increase sampling duration	2% for fibrous media; 10% for non-fibrous media
4. Particle bounce	Systematic	Use dichotomous sampler	Negligible
Laboratory analysis			
5. Instrument error	Random	Planned maintenance, periodic calibration and frequent weight checks	Negligible
6. Filter handling	Random	Use blanks for each test. Control weighing environment for humidity and temperature	2% for hi-vol filters; 5% for lo-vol filters
Emission factor calculation			
7. Poor definition of profile	Random	Sample at 4 or more points over plume dimension of 10 m; 90% of plume mass defined by sampling points	10%
8. Extrapolation of particle size distribution	Random	Assume log-normal particle size distribution	20% for extrapolation to 30 μm. See text.
Total (particles less than 15 μm)			-14% to + 8%[a]

[a] Subsequent field experience in this project (see Section 6) indicated that the dichotomous sampler instrument error was at least 25 percent, producing a total error (for particles less than 15 μm) of 30 to 35 percent.

TABLE 3-7. SUMMARY OF POTENTIAL ERRORS IN THE UPWIND-DOWNWIND SAMPLING METHOD

Source of error	Data restraints to limit error	Estimated error Line source	 Point/area source
Measurement			
1. High volume sampler measurements	Orientation of roof within average wind direction	18.8%	18.8%
2. Wind speed measurement	Average wind speed >1.0 mph	4.6%	4.6%
3. Location relative to the source			
a. Distance from source	Measure from downwind edge of source	1.7%	1.7%
b. Distance from plume ℄ in y dimension	Samplers should be within $2\sigma_y$ of centerline	-	5.8°
c. Distance from plume ℄ in z dimension	Samplers should be within $2\sigma_z$ of centerline	0.5 m	1.0 m
Atmospheric dispersion equation			
4. Initial plume dispersion			
Horizontal		-	0.2 m
Vertical		0.2 m	0.5 m
5. Dispersion coefficients			
Empirical values		3.2%	5.8/3.2%
Estimation of stability class		15.9%	21.1/15.9%
6. Subtraction of a background concentration	This error will be higher when the wind reverses briefly or upwind samplers are biased by nearby sources	18.8%	18.8%
7. Gaussian plume shape		cannot quantify	
8. Steady state dispersion	Marginal passes <12% of good passes	6.0%	6.0%
Total		30.5%	50.1%

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TABLE 3-8. SUMMARY OF TESTS PERFORMED

Sources	Mine 1	Mine 2	Mine 1W[a]	Mine 3	Total
Drill (overburden)	11	-	12	7	30
Blasting (coal)	3	6		7	16
Blasting (overburden)	2			3	5
Coal loading	2	8		15	25
Dozer (overburden)	4	7		4	15
Dozer (coal)	4	3		5	12
Dragline	6	5		8	19
Haul truck	7[b]	9	10	9	35[c]
Light- and medium-duty truck	5	5		3	13[d]
Scraper	5[b]	5	2	2	14
Grader		6		2	8
Exposed area (overburden)	11	14	3	6	34[e]
Exposed area (coal)	10	7	6	16	39
Total	70	75	33	87	265

[a] Winter sampling period.
[b] Five of these tests were comparability tests.
[c] Nine of these were for controlled sources.
[d] Two of these were for controlled sources.
[e] Three of these were for controlled sources.

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SECTION 4

SAMPLE HANDLING AND ANALYSIS

SAMPLE HANDLING

Several different types of particulate samples were collected during the field work: hi-vol glass filters, filters and settling chamber catches from exposure profilers, cascade impactor stages, cyclone precollector catches, Teflon filters from dichotomous samples, Millipore filter cartridges from microscopic analysis, PVC filters from the balloon sampling system, and dustfall samples. These samples all required slightly different handling procedures.

At the end of each run, the collected samples were transferred carefully to protective containers. All transfer operations except removal of cartridges from the instruments were done in a van or in the field lab to minimize sample losses and contamination. Sample media were carried and transported locally in an upright position, and covered with temporary snap-on shields or covers where appropriate. Hi-vol and profiler filters were folded and placed in individual envelopes. Dust collected on interior surfaces of profiler probes and cyclone precollectors was rinsed with distilled water into containers with the settling chamber catches.

In order to reduce the amount of material dislodged from the taut dichotomous filters during handling, the preweighed filters were placed in plastic holders than were then kept in individual petri dishes throughout the handling process. The petri dishes were sealed with tape before being returned to the laboratory and stacked in small carrying cases so that they would not be inverted. Many of the dichotomous filters were hand-carried back to the laboratory by air travel rather than returning with the sampling equipment and other samples in the van.

In spite of the special handling procedures adopted for the dichotomous filters, loose particulate materials was observed in some of the petri dishes and material could be seen migrating across the filter surfaces with any bumping of the filter holder. Several corrective actions were investigated by PEDCo and MRI throughout the study, but this remained an unresolved handling problem. First, ringed Teflon filters were substituted for the mesh-backed filters initially used in an attempt to reduce movement or vibration of the exposed filters. Next, the possibility of weighing the filters in the field was reviewed. However, a sensitive microbalance and strict filter equilibration procedures were required because of the small weights involved--filter tare weights less than 100 mg and may upwind and fine particle fraction sample weighs less than 50 ug. (See Section 12 for further discussion of dichotomous samplers.)

PVC filters for the balloon samplers and Millipore filters for particle size analysis were sent to the field in plastic cartridges. These cartridges were uncapped and affixed to the air pumps during sampling, then resealed and returned to the laboratory for gravimetric or microscopic analysis. Loss of material from these filter surfaces was not observed to be a problem as it was with the Teflon filters.

All samples except the dichotomous filters were labeled with the name of the mine, date, operation, sampler, and a unique sample number (dichotomous sample holders had only the sample number). This same information was also recorded on a field data sheet at the time of sampling. Copies of the field data sheets were shown in the study design report.

To minimize the problem of particle bounce, the glass fiber cascade impactor substrates were greased for use at Mine 3. The grease solution was prepared by dissolving 100 grams of stopcock grease in 1 liter of reagent grade toluene. A low pressure spray gun was used to apply this solution to the impaction surfaces. No grease was applied to the borders and backs of the substrates. After treatment, the substrates were equilibrated and weighed using standard procedures. The substrates were handled, transported and stored in specially designed frames which protected the greased surfaces.

After samples were taken at the mines, they were kept in the field lab until returned to the main laboratory. All samples were accounted for by the field crew by checking against the field data sheet records prior to leaving the field location. Photocopies of the data sheets were made and transported separately from the samples. Upon reaching the lab, the chain of custody was maintained by immediately logging in the sample numbers of all samples received. No sample were known to have been lost through misplacement or inadequate labeling during the entire study.

Non-filter (aggregate) sample were collected during or immediately following each sampling period and labeled with identifying information. The samples were kept tightly wrapped in plastic bags until they were split and analyzed for moisture content. Dried samples were then repackaged for shipment to the main laboratories for sieving.

ANALYSES PERFORMED

Laboratory analyses were performed on particulate samples and on aggregate samples. All monitoring of source activities and meteorological conditions was done with on-site measurements and did not result in the collection of samples for later analysis. The analyses performed are summarized in Table 4-1.

All particulate samples were analyzed in the lab of the by the contractor who took the samples. However, almost all of the aggregate sample analyses were done in the MRI lab because of their extensive past experience with aggregate analyses and to maintain consistency in methods. Aggregate samples for PEDCo's tests were taken by their field crew and moisture contents were determined in the field lab. Most of the labeled, dried aggregate samples were then turned over to MRI for all other analyses.

PEDCo performed all microscopy analyses. Initially, microscopy samples were to be used to determine full particle size distributions. After the comparability study results showed that miscroscopy data did not agree with that obtained from sampling devices that measured aerodynamic particle sizes, the microscopy work was limited to determination of largest particles in the plume downwind of sources.

LABORATORY ANALYSIS PROCEDURES

Filters

Particulate samples were collected on four different types of filters: glass fiber, Teflon, polyvinyl chloride (PVC) and cellulose copolymer (Millipore). The procedure for preparing and analyzing glass fiber filters for high volume air sampling is fully described in Quality Assurance Handbook for Air Pollution Measurement Systems--Volume II, Ambient Air Specific Methods (U.S. Environmental Protection Agency 1977b). Nonstandardized methods were used for the other three filter types. The procedures for each type are described below.

Glass fiber filters were numbered and examined for defects, then equilibrated for 24 hours at 70°F and less than 50 percent relative humidity in a special weighing room. The filters were weighed to the nearest 0.1 mg. The balance was checked at frequent intervals with standard weights to assure accuracy. The filters remained in the same controlled environment for another 24 hours, after which a second analyst reweighed 10 percent of them as a precision check. All the filters in each set in which check weights varied by more than 3.0 mg from initial weights were reweighed. After weighing, the filters were packed flat, alternating with onionskin paper, for shipment to the field.

TABLE 4-1. LABORATORY ANALYSES PERFORMED

Sample	Analysis performed
Particulate	
Hi-vol filter	Weigh, calculate concentration
Exposure profiler filter	Weigh
Settling chamber catch	Filter, dry, weigh
Cyclone precollector catch	Filter, dry, weigh
Cascade impactor stages	Weigh
Quasi-stack filter	Weigh
Settling chamber catch	Transfer, dry, weigh
Teflon filter	Weigh, calculate concentration
PVC filter	Weigh
Millipore filter	Microscopic examination for size distribution and max size
Dustfall	Filter, dry, weigh
Aggregate	
Raw soil sample	Moisture content
Dried sample	Mechanical sieving

When exposed filters were returned from the field, they were equilibrated under the same conditions as the initial weighing. They were weighed and check weighed in the same manner.

Teflon filters from dichotomous samplers were dessicated for 24 hours over anhydrous calcium sulfate (Drierite) before weighing, both before and after use. The filters were weighed in the same constant temperature and humidity room as the glass fiber filters. They were weighed to the nearest 0.01 mg and the check weighing had to agree within 0.10 mg or all filters in the set were reweighed. The filters themselves were not numbered, but were placed in numbered petri dishes for handling and transport. Plastic filter holders were also placed on the filters in the lab so they could be inserted directly into the dichotomous samplers in the field.

PVC filters were treated in exactly the same manner as the Teflon filters, with the exception that they were placed in plastic cartridges rather than petri dishes.

The Millipore filters used for microscopic analysis were not weighed to determine the amount of material collected. After they were exposed and returned to the lab in a plastic cartridge, a radial section of the filter was cut and mounted on a glass miscroscope slide. The filter section was then immersed in an organic fluid that rendered it invisible under the microscope, and a cover slip was placed over it. The slide was examined under a light microscope at 100 power using phase contract illumination. The particles were sized by comparison with a calibrated reticle in the eyepiece. Ten different fields and at least 200 particles were counted on each slide. Also, the diameters of the three largest individual particles observed were recorded.

Settling Chamber Catches and Dustfall Samples

Laboratory grade deonized distilled water was used in the field laboratory to recover samples from settling chambers and dustfall buckets. Each unit was thoroughly washed five to eight separate times. A wash consisted of spraying 15 to 25 ml water into the unit, swirling the unit around, and then quantitatively pouring the water into a sample jar (holding 150 ± 50 ml of wash water) was sealed and packed for shipping to MRI for sample recovery.

At the MRI laboratory, the entire wash solution was passed through a 47 mm Buchner type funnel holding a Type AP glass fiber filter under suction. The sample jar was then rinsed twice with 10 to 20 ml of deonized water. This water was passed through the Buchner funnel ensuring collection of all suspended material on the 47 mm filter. The tared filter was then dried in an oven at 100°C for 24 hours. After drying, the filters were conditioned at constant temperature 24 ± 2°C and constant humidity 45 ± 5 percent relative humidity for 24 hours.

All filters, both tared and exposed, were weighed to ±5 μg with a 10 percent audit of tared and exposed filters. Audit limits were ±100 μg. Blank values were determined by washing "clean" (unexposed) settling chambers and dustfall buckets in the field and following the above procedures.

Aggregate Samples

Samples of road dust and other aggregate materials were collected in 20 to 25 kg quantities for analysis of moisture and silt content. The samples were stored briefly in airtight plastic bags, then reduced with a sample splitter (riffle) or by coning and quartering to about 1 kg (800 to 1600 g).

The final split samples were placed in a tared metal pan, weighed on a balance, and dried in an oven at 110°C overnight. Laboratory procedures called for drying of materials composed of hydrated materials or organic materials like coal and certain soils for only 2 hours. The samples were then reweighed and the moisture content calculated as the weight loss divided by the original weight of the sample alone. This moisture analysis was done in the field lab.

Dried samples were placed in plastic containers and sealed for shipment to main laboratories for determination of silt contents. This was done by mechanical dry sieving, with the portion passing a 200-mesh screen constituting the silt portion. The nest of sieves was placed on a conventional sieve shaker for 15 min. The material passing the 200-mesh screen, particles of less than 75 μm diameter, constituted the smallest particles which could be accurately determined by dry sieving according to ASTM methods.

More detailed sample collection and laboratory procedures for the moisture and silt analyses were presented in an appendix to the study design report.

QUALITY ASSURANCE PROCEDURES AND RESULTS

Quality assurance was an important concern from the beginning of this field study because of its size, complexity, and importance. Several special activities were instituted as part of the overall quality assurance effort. The primary one was delineation of specific assurance procedures to be followed throughout the study. This list of procedures was subjected to review by the technical review group; a revised version is presented in Table 4-2. It covers sampling rates, sampling media, sampling equipment and data calculations.

In addition to the quantitative checks listed in Table 4-2, many nonquantifiable procedures related to sample handling and visual inspection of equipment were adopted. Some of these were based on standard practices but others were set more stringent than normal requirements. No quality assurance procedures for operating or maintaining dichotomous samplers had been recommended yet by EPA, so considerable project effort was expended in developing and testing these procedures.

Meteorological equipment and monitoring procedures are not covered in Table 4-2. Approved equipment was used and it was operated and maintained according to manufacturer's instructions. Meteorological instruments had been calibrated in a laboratory wind tunnel prior to the field work.

Adherence to the specified quality assurance procedures was checked periodically by the Project Officer and other members of the technical review group, by intercontractor checks, and by external independent audits. Results of the quality assurance program for flow rates and weighing are summarized in Table 4-3. Results of the audits are described in the following section.

AUDITS

In addition to the rigorous internal quality assurance program and the review procedures set up with the technical review group, several independent audits were carried out during this study to further increase confidence in results. Two different levels of audits were employed:

Intercontractor - MRI audited PEDCo and vice versa

External - Performed by an EPA instrument or laboratory expert or a third EPA contractor

The audit activities and results of audits are summarized in Table 4-4.

Although there are no formal pass/fail criteria for audits such as these, all of the audits except the collocated samplers in the comparability study and filter weighings seemed to indicate that measurements were being made correctly and accurately. The collocated sampler results are discussed further in Section 6 and 12. All the filters that exceeded allowable tolerances upon reweighing (10 percent of audited filters) lost weight. In the case of the hi-vol filters, loose material was observed in the filter folders and noted on the MRI data sheet. The amounts lost from the dichot filters would not be as readily noticeable in the petri dishes. The several extra handling steps required for auditing the filters, including their transport from Cincinnati to Kansas City, could have caused loss of material from the filters.

In addition to the external flow calibration audit at the third mine (shown in Table 4-4), another one was conducted at the second mine. However, results of this earlier audit were withdrawn by the contractor who performed

TABLE 4-2. QUALITY ASSURANCE PROCEDURES FOR MINING EMISSION FACTOR STUDY

Activity	QA check/requirement
Sampling flow rates	
Calibration	
Profilers, hi-vols, and impactors	Calibrate flows in operating ranges using calibration orifice, once at each mine prior to testing.
Dichotomous samplers	Calibrate flows in operating ranges with displaced volume test meters once at each mine prior to testing.
Single-point checks	
Profilers, hi-vols, and impactors	Check 25% of units with rotameter, calibration orifice, or electronic calibrator once at each site prior to testing (different units each time). If any flows deviate by more than 7%, check all other units of same type and recalibrate non-complying units. (See alternative check below).
Dichotomous samplers	Check 25% of units with calibration orifice once at each site prior to testing (different units each time). If any flows deviate by more than 5%, check all other units and recalibrate non-complying units.
Alternative	If flows cannot be checked at test site, check all units every two weeks and recalibrate units which deviate by more than 7% (5% for dichots).
Orifice calibration	Calibrate against displaced volume test meter annually.
Sampling media	
Preparation	Inspect and imprint glass fiber media with ID numbers. Inspect and place Teflon media (dichot filters) in petri dishes labeled with ID numbers.
Conditioning	Equilibrate media for 24 hours in clean controlled room with relative humidity of less than 50% (variation of less than ±5%) and with temperature between 20°C and 25°C (variation of less than ±3%).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.1 mg and weigh dichot filters to nearest 0.01 mg.

(continued)

TABLE 4-2 (continued).

Activity	QA check/requirement
Auditing of weights (tare and final)	Independently verify weights of 7% of filters and substrates (at least 4 from each batch). Reweigh batch if weights of any hi-vol filters or substrates deviate by more than ±3.0 mg or if weights of any dichot filters deviate by more than ±0.1 mg.
Correction for handling effects	Weigh and handle at least one blank for each 10 filters or substrates of each type for each test.
Prevention of handling losses	Transport dichot filters upright in filter cassettes placed in protective petri dishes.
Calibration of balance	Balance to be calibrated once per year by certified manufacturers representative. Check prior to each use with laboratory Class S weights.
Sampling equipment	
Maintenance	
All samplers	Check motors, gaskets, timers, and flow measuring devices at each mine prior to testing.
Dichotomous samplers	Check and clean inlets and nozzles between mines.
Equipment siting	Separate collocated samplers by 3-10 equipment widths.
Operation	
Isokinetic sampling (profilers only)	Adjust sampling intake orientation whenever mean (15 min average) wind direction changes by more than 30 degrees.
	Adjust sampling rate whenever mean (15 min average) wind speed approaching sampler changes by more than 20%.
Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.
Data calculations	
Data recording	Use specially designed data forms to assure all necessary data are recorded. All data sheets must be initialed and dated.
Calculations	Independently verify 10% of calculations of each type. Recheck all calculations if any value audited deviates by more ±3%.

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TABLE 4-3. QUALITY ASSURANCE RESULTS

Activity	QA results
Calibration	
Profilers, hi-vols, and impactors	PEDCo calibrated hi-vols a total of 6 times in the 4 visits. MRI had flow controllers on all 3 types of units. These set flows were calibrated a total of 4 times for profilers, 7 times for hi-vols and impactors.
Dichotomous samplers	PEDCo and MRI calibrated their 9 dichots a total of 6 times, at least once at each mine visit. Actual flow rates varied as much as 9.1% between calibrations.
Single point checks	
Profilers, hi-vols, and impactors	Out of a total of 29 single point checks, only 2 PEDCo hi-vols were found to be outside the 7% allowable deviation, thus requiring recalibration. For MRI, 20 single point checks produced no units out of compliance.
Dichotomous samplers	The dichotomous samplers were recalibrated with a test meter each time rather than checking flow with a calibrated orifice.
Weighings	
Tare and final weights	PEDCo reweighed a total of 250 unexposed and exposed hi-vol filters during the study. Three of the reweighings differed by more than 3.0 mg. For 238 dichot filter reweighings, only four differed by more than 0.1 mg. MRI reweighed a total of 524 unexposed and exposed glass fiber filters during the study. Four of the reweighings differed by more than 3.0 mg. For 43 dichot filter reweighings, only one differed by more than 0.1 mg.
Blank filters	PEDCo analyzed 88 blank hi-vol and 69 blank dichot filters. The average weight increase was 3.4 mg (0.087%) for hi-vols, 0.036 mg (0.038%) for dichots. The highest blanks were 26.3 and 0.22 mg, respectively. MRI analyzed 67 hi-vol and dichot filter blanks. The highest blanks were 7.05 mg and 0.52 mg, respectively.

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TABLE 4-4. AUDITS CONDUCTED AND RESULTS

Activity	Inter-contractor or external audit	Contractor audited	Date	No. and type of units	Results
Flow calibration	I	PEDCo	8-22-79	2 hi-vol	Each 4% from cal. curve
		MRI	8-27-79	1 hi-vol 1 impactor 2 dichot	Hi-vol and impactor within 4% of curve; dichot within 2%
		PEDCo	10-12-79	2 hi-vol	One within 1%, other out by 12.6%
		MRI	10-12-79	2 hi-vol 1 dichot	Both within 7% Within 5%
	E (EPA, OAQPS)	PEDCo	8-01-79	7 dichot	All set 5 to 11% high
		MRI	8-01-79	2 dichot	One within 1%, other out by 10%
	E (contractor)	MRI	8-06-80		
		PEDCo	8-05-80	10 hi-vol	7 within 5%, 2 within 7%, one 8.3% from cal. curve
		PEDCo	8-06-80	5 dichot	Total flows all within 5%, 2 coarse flows differed by 6.2 and 9.2%
Filter weighing	I	PEDCo	1-02-80	39 hi-vol 31 dichot	Three hi-vol filters varied by more than 5.0 mg; all lost weight and loose material in folder was noted. Four dichots exceeded the 0.10 mg tolerance and all lost weight
		MRI	-		Filters not submitted yet
Laboratory procedures	E (EPA, EMSL)	PEDCo	10-30-79	Compreh. review	No problems found
		MRI	11-13-79	Compreh. review	No problems found
Collocated samplers	I	Both	7-26-79 to 8-09-79	18 hi-vol 10 dichot	Paired hi-vol values differed by an av of 34%; IP values by 35%.
Systems audit	E (EPA, OAQPS)	Both	8-01-79	All	Checked siting, calibration, filter handling, and maint. procedures. Few minor problems found but concluded that operations should provide reliable data.

it after it was learned that some critical steps, such as the auditee being present and current calibration curves being provided at the time of the audit, had not been followed. However, the preliminary results of that withdrawn audit showed generally acceptable performance of almost all the sampling equipment.

Some of the calculations of each contractor were repeated by the other as an audit activity. In general, the data were found to be free of calculation errors, but differences in assumptions and values read from curves led to frequent differences in final emission rates. No effort was made to estimate the average difference in independently calculated emission rates.

SECTION 5

CALCULATION AND DATA ANALYSIS METHODOLOGY

NUMBER OF TESTS PER SOURCE

The study design proposed the number of samples to be collected for each operation, but these initial numbers were based primarily on available sampling time and the relative importance of each operation as a dust source. Several members of the technical review group requested a statistical analysis to determine the appropriate number of samples to be taken.

After sampling data were obtained from the first two mines/three visits, the total sample size needed to achieve a specified margin of error and confidence level could be calculated by knowing the variability of the partial data set. This method of estimating required sample size, in which about half of the preliminarily-estimated sample size is taken and its standard deviation is used to provide a final estimate of sample size, is called the two-stage or Stein method. The two-stage method, along with two preliminary data evaluations, constituted the statistical plan finally prepared for the study.

The steps in estimating total sample sizes and remaining samples in the statistical plan were:

1. Determine (by source) whether samples taken in different seasons and/or at different mines were from the same population. If they were, total sample size could be calculated directly.
2. Evaluate potential correction factors. If samples were not from a single distribution, significant correction factors could bring them into a single distribution. If they were from populations with the same mean, correction factors could reduce the residual standard deviations.
3. Calculate required sample sizes using residual standard deviations.
4. Calculate remaining samples required to achieve the desired margin of error and confidence level and recommend the number of samples for each source to be taken at the third mine.

Two-Stage Method for Estimating Sample Size

If samples are to be taken from a single normal population, the required total sample size can be calculated with the following equation based on the two-stage sampling method (Natrella 1963):

$$n = \frac{t^2 s_1^2}{d^2} \qquad \text{(Eq. 1)}$$

where n = number of samples required for first and second stages combined

s_1 = estimate of population standard deviation based on n_1 samples

t = tabled t-value for risk a and n_1-1 degrees of freedom

d = margin of error in estimating population mean

The margin of error, d, and the risk, a, that the estimate of the mean will deviate from the population mean by an amount d or greater are specified by the user. A relative error ($d/\bar{x}$) of 25 percent and a risk level of 20 percent have been specified for the calculations presented herein based on the intended use for the results, the measurement errors involved in obtaining the samples, and the accuracy of emission factors currently being used for other sources. Having specified d (or $d/\bar{x}$) and a, the only additional value needed to calculate n for each source is the estimate of population standard deviation, s_1 (or $s_1/\bar{x}$), based on the partial sample obtained to date, n_1.

Samples from the Same Normal Population

One important restriction on the use of Equation 1, as noted above, is that samples (from different mines) must be from a single normal distribution. If average emission rates for a specific source at three different mines are 2, 10, and 50 lb/ton, and the three samples have relatively low variability, the combined data cannot be assumed to be normally distributed with a common mean. Regardless of how many samples were taken at each mine, the data would be trimodally distributed.

Therefore, before Equation 1 can be used to calculate the total sample size, a check should be performed to determine whether the available data from different mines are from populations with the same mean and variance. If not, the mines would need to be treated separately and thus require a calculation of required sample size for each mine, using the analogue of Equation 1 (n = number of samples at a single mine). The total sample size would then be the total of the three sample sizes calculated for the respective mines.

A statistical test can be performed on the data to evaluate whether two or more sets of samples taken at different mines or in different seasons are from distributions (populations) having the same means and variances (Natrella 1963; Hald 1952).* This test was performed in the statistical plan and indicated that all sources at the first two mines/three visits except coal dozers, haul roads, and overburden drills were from the same populations. Therefore, with the exceptions noted, total sample sizes could be determined directly.

Correction Factors

This approach on which this study has been based is that the final emission factors will be mean emission rates with correction factors attached to adequately account for the wide range of mining and meteorological conditions over which the emission factors must be applied. The use of correction factors may affect required sample sizes, in that correction factors which reduce the uncertainty (standard deviation) in estimating an emission factor also reduce the sample size necessary to attain a desired precision with a specified confidence. Therefore, the partial data from two mines were analyzed for significant correction factors that could reduce the sample standard deviations and thus possibly reduce required sample sizes. It should be pointed out that some additional samples are needed to adequately quantify the effect of each correction factor on the emission factor, so a small reduction in sample size due to the use of a correction factor would be offset by this need for extra data.

Independent variables thought to be candidates for correction factors were measured or monitored with each sample of emission rate. The potential correction factors are listed in Table 5-1.

The approach for evaluation of correction factors described later in this section, multiple linear regression, was used to identify significant correction factors in the partial data set. However, analysis was not as thorough (e.g., did not include transformations) because it was being done only to get a slightly better estimate of the optimum sample size.

The independent variables considered and their effects on standard deviation are summized in Table 5-1. Using appropriate values of s (standard deviaiton) in Equation 1, the sample sizes consistent with the previous-discussed relative error of 25 percent and risk level of 20 percent were calculated. These numbers are shown in Table 5-2, which was taken from the statistical plan. Some $\overline{x}$ and s values in this table may not agree exactly with values reported later in the results sections because of minor changes in calculation procedures between the time the statistical plan (e.g., method of extrapolating to 30 µm SP emission rate) was released and the final report was prepared.

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* Another test, the x^2 test for goodness of fit, may be more appropriate for determining whether data are from a population with a normal distribution, but it was not used in the original statistical plan.

These sample sizes were calculated after 2 mines/3 visits, leaving only one mine visit to obtain all the additional samples. It was not possible to complete the sampling requirements specified in Table 5-2 at the third mine within available project resources. Therefore, an attempt was made to get relative errors for all sources down to 0.31 and major sources (haul trucks, scrapers, and draglines) down to 0.25 by slightly reallocating the number of samples required for several of the sources. Table 5-3 compares four different sets of sample sizes:

1. Originally proposed in study design.
2. Calculated after 2 mines/3 visits to achieve a relative error of 25 percent at risk level of 0.20.
3. Proposed in statistical plan as feasible totals after third mine.
4. Actually collected at 3 mines/4 visits.

CALCULATION PROCEDURES

Exposure Profiling

To calculate emission rates using the exposure profiling technique, a conservation of mass approach is used. The passage of airborne particulate, i.e., the quantity of emissions per unit of source activity, is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Th exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement. The steps in the calculation procedure are presented in the paragraphs below.

Step 1 Calculate Weights of Collected Sample--

In order to calculate the total weight of particulate matter collected by a sample, the weights of air filters and of intake wash filters (profiler intakes and cyclone precollectors only) are determined before and after use. The weight change of an unexposed filter (blank) is used to adjust for the effects of filter handling. The following equation is used to calculate the weight of particulate matter collected.

TABLE 5-1. EVALUATION OF CORRECTION FACTORS WITH PARTIAL DATA SET

Source/ samples	Potential correction factor	Mult. R	Significance	Relative std deviation
				0.838
Overburden drilling/23	Silt	0.58	0.004	0.699
	Depth of hole	0.63	0.161	0.681
	% moisture	0.63	0.809	0.697
				1.037
Blasting (coal)/9	No. of holes	0.47	0.199	0.977
	% moisture	0.48	0.860	1.053
				1.149
Coal loading/10	Bucket capacity	0.39	0.264	1.122
				0.784
Dozer (~~ovbd~~)/11 overburden	Speed	0.61	0.048	0.657
	Silt	0.69	0.239	0.636
	% moisture	Did not improve regression		
				0.695
Dozer (coal)/7	Speed	0.84	0.019	0.416
	Silt	Did not improve regression		
	% moisture	Did not improve regression		
				1.446
Dragline/11	Drop distance	0.88	0.000	0.733
	% moisture	0.91	0.120	0.662
	Bucket capacity	0.92	0.334	0.659
	Operation	0.96[a]	0.048[a]	0.500
	Silt	Did not improve regression		
				1.470
Haul truck/18	Silt	0.40	0.048	1.377
	No. of passes	0.46	0.074	1.364
	Control	0.47	0.148	1.387
	Moisture	0.48	0.258	1.419
Lt.- and med.-duty vehicles/6	Veh. weight (added to above)	0.54[b]	0.280	1.076[b]
				0.888
Scraper/ 12	Silt	0.15	0.649	0.922
	% moisture	0.20	0.827	0.961
	No. of passes	0.28	0.877	1.000
Grader/5	Not enough data			

[a] Interrelated with drop distance, so not used as a correction factor.

[b] The four variables for haul roads all explained more variance than vehicle weight, and it did not reduce residual coefficient of variation for combined haul road/access road data set.

TABLE 5-2. CALCULATED SAMPLE SIZES USING TWO-STAGE METHOD

Source	Single pop.	First est.	n_1	$t_{0.8}$[a]	s[b]	$\bar{x}$	$s/\bar{x}$	n, per mine	n, total
Drilling	no	40	11 12	1.383 1.372	From Table 5-1 From Table 5-1		0.70 0.70	15 15	45
Blasting (coal)	yes	12	9	1.397	18.7	18.0	1.04		34
Coal loading	yes	30	10	1.383	0.031	0.027	1.15		41
Dozer (ovbd)	yes	18	11	1.383	From Table 5-1		0.66		14
Dozer (coal)	no	18	4 3	1.638 1.886	8.97[b] 3.01[b]	25.4 6.54	0.35 0.46	6[b] 12[b]	27
Dragline	yes	18	11	1.383	From Table 5-1		0.73		17
Haul truck (PEDCo est.)	no	30	5 6	1.533 1.476	4.54 10.37	9.67 19.20	0.47 0.54	9 11	30
Haul truck IP (MRI est.)	no	30	6 6	1.476 1.476	3.99 0.62	6.68 1.56	0.60 0.40	13 6	29
Lt.- and med.-duty vehicles	yes	15	5	1.533	3.30	2.87	1.15		50
Scraper	yes	18	12	1.363	13.99	15.75	0.89		24
Grader	?	9	5	1.533	0.90	1.7	0.53		11

[a] Degrees of freedom (d.f.) for calculating t are n_1-1 unless there are correction factors, in which case d.f. are reduced by 1 for each correction factor.

[b] Smaller sample sizes are required without use of correction factor for speed.

TABLE 5-3. SAMPLE SIZES PROPOSED AND OBTAINED

Source	Samples proposed in study dsn	Samples required by 2-stage method	Samples proposed in stat plan	Rel. error for samples in stat plan	Samples actually collected
Drilling	40	45	30	0.20	30
Blasting (coal)	12	34	16	0.36	16
Coal loading	30	41	24	0.32	25
Dozer (ovbd)	18	14	16	0.31	15
Dozer (coal)	18	27	10	0.31	12
Dragline	18	17	19	0.21	19
Haul truck	30	30	40	0.19	36
Lt.- and med.-duty vehicles	15	50	12[a]	0.45[a]	12
Scrapers	18	24	24	0.24	15
Graders	9	11	8	0.27	7

[a] Expected to be combined with haul roads in a single emission factor.

$$\begin{array}{l} \text{Particulate} \\ \text{sample} \\ \text{weight} \end{array} = \begin{array}{l} \text{Final} \\ \text{filter} \\ \text{weight} \end{array} - \begin{array}{l} \text{Tar} \\ \text{filter} \\ \text{weight} \end{array} - \begin{array}{l} \text{Fianl} \\ \text{blank} \\ \text{weight} \end{array} - \begin{array}{l} \text{Tare} \\ \text{blank} \\ \text{weight} \end{array} \qquad \text{(Eq. 2)}$$

Because of the typically small factions of finds in fugitive dust plumes and the low sampling rate of the dichotomous sampler, no weight gain may be detected on the fine filter of this instrument. This makes it necessary to estimate a minimum detectable FP concentration corresponding to the minimum weight gain which can be detected by the balance (0.005 mg). Since four individual tare and final weights produce the particualte sample weight (Equation 2), the minimum detectable weight on a filter is 0.01 mg.

To calculate the minimum FP concentration, the sampling rate (1 m^3/h) and duration of sampling must be taken into account. For example, the minimum concentration which can be detected for a one-hour sampling period is 10 $\mu g/m^3$. The actual sampling time should be used to calculate the minimum concentration.

Step 2 Calculate Particulate Concentrations--

The concentration of particulate matter measured by a sampler, expressed in units of micrograms per standard cubic meter (μg/scm), is given by the following equation.

$$C_s = 3.53 \times 10^4 \frac{m}{Q_s t} \qquad \text{(Eq. 3)}$$

where C_s = particulate concentration, μg/scm

m = particulate sample weight, mg

Q_s = sampler flow rate, SCFM

t = duration of sampling, min

The coefficient in Equation 3 is simply a conversion factor. To be consistent with the National Ambient Air Quality Standard for TSP, all concentrations are expressed in standard conditions (25°C and 29.92 in. of Hg).

The specific particulate matter concentrations are determined from the various particulate catches as follows:

TP - Profiler: filter catch + intake catch
or
Cyclone/cascade impactor: cyclone catch + substrate catches + backup filter catch

TSP -	Hi-vol sampler:	filter catch
SP -	Calculated:	sub-30 µm fraction determined by extrapolation of sub-2.5 and sub-15 µm fractions assuming a lognormal size distribution
IP -	Size-selective inlet:	filter catch
	Dichotomous sampler:	coarse particualte filter catch + fine particulate filter catch
FP -	Dichotomous sampler:	fine particle filter catch multiplied by 1.11

The dichotomous sampler total flow of 1 m^3/h is divided into a coarse particle flow of 0.1 m^3/h and a fine particle flow of 0.9 m^3/h. The mass collected on the fine particle filter is adjusted for fine particles which remain in the air stream destined for the coarse particle filter.

Upwind (background) concentrations of TP or any of the respective size fractions are substracted from corresponding downwind concentrations to produce "net" concentrations attributable to the tested source. Upwind sampling at one height (2.5 meters) did not allow determination of vertical variations of the upwind concentration. Because the upwind concentration at 2.5 meters may be greater than at the 4 to 6 meter height of the net downwind profiling tower, this may cause a downward bias of the net concentration. Upwind TP is preferably obtained with an isokinetic sampler, but should be represented well by the upwind TSP concentration measured by a standard hi-vol, if there are not nearby sources that would have a coarse particle impact on the background station.

Step 3 Calculate Isokinetic Flow Ratios--

The isokinetic flow ratio (IFR) is the ratio of the sampler intake air speed to the wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q}{aU} = \frac{Qs}{aU_s} \qquad \text{(Eq. 4)}$$

where Q = sampler flow rate, ACFM

Q_s = sampler flow rate, SCFM

a = intake area of sampler, ft^2

U = approaching wind speed, fpm

U_s = approaching wind speed, sfpm

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IFR is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias.

Step 4 Calculate Downwind Particle Size Distributions--

The downwind particle size distribution of source--contributed particulate matter at a given height may be calculated from net TP, IP, and FP concentrations at the same height (and distance from the source). Normally, the TP value from the exposure profiler head would be used, unless a cascade impactor operates much closer to isokinetic sampling conditions than the exposure profiler head.

The proper inlet cut-point of each dichotomous sampler must be determined based on the mean wind speed at the height of the sampler. The concentration from a single upwind dichotomous sampler should be adequately representative of the background contribution to the downwind dichotomous sampler concentrations. The reasons are: (a) the background concentration should not vary appreciably with height; (b) the upwind sampler, which is operated at an intermediate height, is exposed to a mean wind speed which is within about 20 percent of the wind speed extremes that correspond to the range of downwind sampler heights; and (c) errors resulting from the above conditions are small because of the typically small contribution of background in comparison to the source plume.

Independent particle size distributions may be determined from a cascade impactor using the proper 50 percent cutoff diameters for the cyclone precollector and each impaction stage. Corrections for coarse particle bounce are recommended.

If it can be shown that the FP and apparent IP fractions of the net TP concentrations do not vary significantly with height in the plume, i.e., by more than about 10 percent, then the plume can be adequately characterized by a single particle size distribution. This size distribution is developed from the dichotomous sampler net concentrations. The fine particle cutpoint of the dichotomous sampler (2.5 µm) corresponds to the midpoint of the normally observed bimodel size distribution of atmospheric aerosol. The coarse mode represents particles produced by a single formation mechanism and can be expected to consist of particles of lognormally distributed size. The best fit lognormal line through the data points (mass fractions of TP) is determined using a standard linear regression on transformed data points as described by Reider and Cowherd (1979). This best fit line is extrapolated or interpolated to determine SP and IP fractions of TP.

Step 5 Calculate Particulate Exposures and Integrate Profiles--

For direction samplers operated isokinetically, particulate exposures may be calculated by the following equation:

$$E = \frac{M}{a} = 2.83 \times 10^{-5} \frac{C_sQ_st}{a} \qquad \text{(Eq. 5)}$$

$$+ 3.05 \times 10^{-8} C_sU_st \qquad \text{(Eq. 6)}$$

where E = particulate mass collected by sampler, mg

M = net particulate mass collected by sampler, mg

a = sampler intake area, cm^2

C_s = net particulate concentration, $\mu g/sm^3$

U_s = approaching wind speed, sfpm

Q_s = sampler flow rate, SCFM

t = duration of sampling, min

The coefficients of Equations 5 and 6 are conversion factors. Net mass or concentration refers to that portion which is attributable to the source being tested, after subtraction of the contribution from background.

Note that the above equations may also be written in terms of test parameters expressed in actual rather than standard conditions. As mentioned earlier, the MRI profiler heads and warm-wire anemometers give readings expressed at standard conditions.

The integrated exposure for a given particle size range is found by numerical integration of the exposure profile over the height of the plume. Mathematically, this is stated as follows:

$$A = \overset{H}{\underset{0}{}} \quad Edh \qquad \text{(Eg. 7)}$$

where A = integrated exposure, m-mg/cm^2

E = particulate exposure, m-mg/cm^2

h = vertical distance coordinate, m

H = effective extent of plume above ground, Physically, A represents the total passage of airborne particulate matter downwind of the source, per unit length of line source.

The net exposure must equal zero at the vertical extremes of the profile, i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentrations equals zero. The maximum TP exposure usually occurs below a height of 1 m, so that there is a sharp decay in TP exposure near the ground. The effective height of the plume is determined by extrapolation of the two uppermost net TSP concentrations.

Integration of the portion of the net TP exposure profile that extends above a height of 1 m is accomplished using Simpson's Rule on an odd number of equally spaced exposure values. The maximum error in the integrated exposure resulting from extrapolation above the top sampler is estimated to be one-half of the fraction of the plume mass which lies above the top sampler. The portion of the profile below a height of 1 m is adequately depicted as a vertical line representing uniform exposure, because of the offsetting effects of the usual occurrence of maximum exposure and the decay to zero exposure at ground level (see Figure 5-1).

Step 6 Calculate Particulate Emission Rates--

The TP emission rate for airborne particulate of a given particle size range generated by vehicles traveling along a straight-line road segment, expressed in pounds of emissions per vehicle-mile traveled (VMT), is given by:

$$e = 35.5 \frac{A}{N} \qquad \text{(Eq. 8)}$$

where e = particulate emission rate, lb/VMT

A = integrated exposure, m-mg/cm^2

N = number of vehicle passes, dimensionless

The coefficient of Equation 8 is simply a conversion factor. The metric equivalent emission rate is expressed in kilograms (or grams) of particulate emissions per vehicle-kilometer traveled (VKT).

The SP, IP, and FP emission rates for a given test are calculated by multiplying the TP emission rate by the respective size fractions obtained in Step 4.

Dustfall flux decays with distance downwind of the source, and the flux distribution may be integrated to determine the portion of the TP emission which settles out near the source. Although this effect has been analyzed in

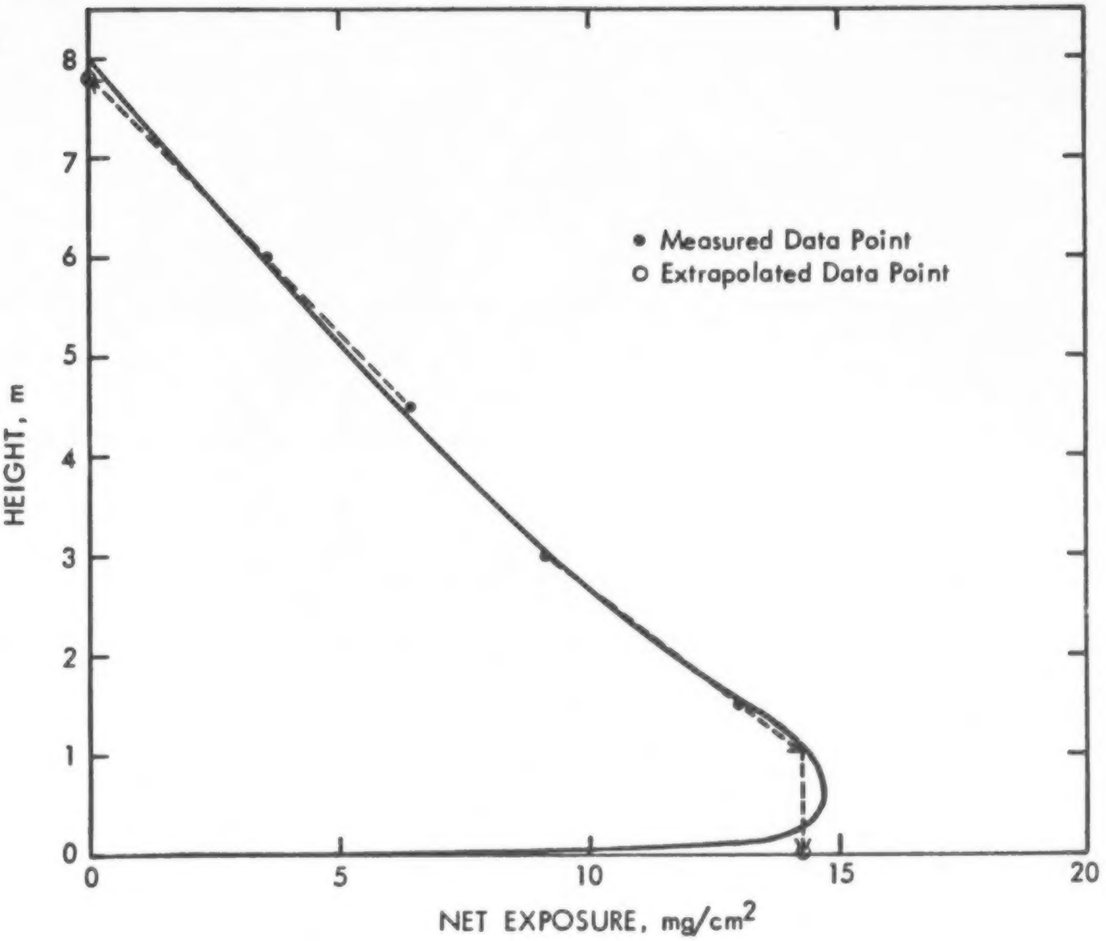

Figure 5-1. Illustration of exposure profile extrapolation procedures (haul truck run J-9).

previous studies, it is not essential to the reduction of profiling data. Consequently, no such analysis is being performed in the present study as part of the profiling calculations.

Upwind-Downwind

The basis for calculation of emission rates in the upwind-downwind sampling method is conversion of ambient concentration data into corresponding emission rates by use of a Gaussian dispersion equation. Two different forms of the Gaussian dispersion equation were used--one for line source and the other for point sources. In both cases, net downwind (downwind minus upwind) concentrations were substituted into the equation along with appropriate meteorological and distance data to calculate apparent source strengths. The eight to 10 samplers in the downwind array resulted in that number of estimates of source strength being produced for each sampling period.

In an interim technical report, the calculation procedures for the upwind-downwind method were explained in slightly greater detail than has been allocated in this report. A step-by-step calculation procedure was presented in the interim report and is summarized below:

1. Determine stability class by σ_θ method.
2. Calculate initial plume dispersion, σ_{y0} and σ_{z0}.
3. Determine virtual distance x_0.
4. Determine source-to-sampler distances.
5. Calculate plume dispersion (o_y and o_z) at each downwind sampling distance.
6. Correct measured concentrations for distance of sampler away form plume centerline (for point sources only).
7. Calculate source strength with Gaussian dispersion equation.
8. Convert source strength to an emission rate.

These steps are discussed briefly below.

Step 1 Determine the Stability Class--

Stability class was calculated using the σ_θ method. A σ_θ value was determined for each test period by the method described on the following page. Stability class was then estimated as presented in Table 5-4. An alternate method of estimating stability, based on wind speed and cloud cover, always agreed within half a stability class with the σ_θ method value.

TABLE 5-4. σ_θ METHOD OF DETERMINING ATMOSPHERIC STABILITY CLASS

σ_θ	Stability class
$\sigma_\theta > 22.5°$	A
$17.5 < \sigma_\theta < 22.5$	B
$12.5 < \sigma_\theta < 17.5$	C
$\sigma_\theta < 12.5$	D

(σ_θ <7.5° would be E stability, but D would be used because all sampling occurred during daytime and E is only a nighttime stability class).

Source: Mitchell 1979.

Steps 2 through 5 Calculate Plume Dispersion Coefficients (o_y and o_z)--

Value of o_y and o_z are a function of downwind distance, x, and stability class. For distances greater that 100 m, Pasquill's dispersion curves can be used to determine values of o_y and o_z (Turner 1970, pp-8-9). For distances less than 100 m, and the following equations were utilized:

$$o_y = \frac{o_0}{57.3}(x) + o_{yo} \qquad \text{(Eq. 9)}$$

$$o_z = a(x + x_0)^b \qquad \text{(Eq. 10)}$$

The variables in Equations 9 and 10 were determined as follows:

σ_θ - The σ_θ value is the standard deviation of horizontal wind direction and was obtained by dividing the wind direction strip chart recording for the test period into increments of 1 min each, specifying an average direction each increment, and calculating the standard deviation of the resulting set of readings. The upper limit of σ_θ for use in Equation is 32°.

x - The source-to-sampler distance was measured in the field and later obtained from the sketch of the sampling setup for each test. It is the straight line distance from the source to the sampler rather than the perpendicular distance from the source to a row of samplers.

σ_{yo} - Initial horizontal plume dispersion is the initial plume width divided by 4.30 (Turner 1970). The average initial plume width was observed and recorded during sampling. Photographs were also taken.

a,b - These are empirically-derived dispersion coefficients that are only applicable within 100 m of a ground-level source (Zimmerman and Thompson 1975). The coefficients are a function of stability class:

Stability class	a	b
A	0.180	0.945
B	0.145	0.932
C	0.110	0.915
D	0.085	0.870

x_o - The virtual distance term, x_o, is used to simulate the effect of initial vertical plume dispersion. It is estimated from the initial vertical plume dispersion value, σ_{zo}, which in turn is the observed initial plume height divided by 2.15 (Turner 1970):

$$x_o = \sqrt[b]{\sigma_{zo}/a}$$

Step 6 Correct Concentrations for Distance of Sampler Away from Plume Centerline--

The dispersion equations assume that sampling is done along the plume centerline. For line sources, this is a reasonable assumption because the emissions occur at ground level and have an initial vertical dispersion (σ_{zo}) of 3 to 5 m. Therefore, the plume centerline is about 2.5 m height, the same as the sampler heights. Field personnel attempted to position samplers so that this relationship was maintained even in rough terrain. Horizontal dispersion does not enter into the calculation for line sources.

For point sources, it is not possible to sample continuously along the plume centerline because of varying wind directions and possibly because of varying emission heights (e.g., shovels and draglines). The problem of varying wind direction was accounted for by first determining the resultant wind direction relative to the line of samplers, trigonometrically calculating the horizontal distance from the sampler to the plume centerline (y), and then determining the reduction from centerline concentration with the following equation:

$$\text{reduction factor}_y = e^{-\frac{1}{2}\left[\left(\frac{y}{\sigma_y}\right)^2\right]} \qquad \text{(Eq. 11)}$$

Differences in the height of sampling and height of emission release were accounted for in the point source dispersion equation with an additional exponential expression when the average difference in height could be determined. Field personnel noted heights of emission release on data sheets for later use in dispersion calculations. The exponential expression used to determine the reduction from centerline concentration is:

$$\text{reduction factor}_z = e^{-\frac{1}{2}\left[\left(\frac{H}{\sigma_z}\right)^2\right]} \qquad \text{(Eq. 12)}$$

where H = average vertical distance from plume centerline to samplers, m

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Step 7 Calculate Source Strength with Gaussian Dispersion Equation--

The line source equation was used for haul road, scraper, and some dozer sources. The equation is:

$$\chi = \frac{2q}{\sin \phi \sqrt{2\pi} \; \sigma_z \; u} \qquad \text{(Eq. 13)}$$

where χ = plume centerline concentration at a distance x downwind from the mining source, g/m^3

q = line source strength, g/s-m

ϕ = angle between wind direction and line source

σ_z = the vertical standard deviation of plume concentration distribution at the downwind distance x for the prevailing atmospheric stability, m

u = mean wind speed, m/s

The point source dispersion equation was used in conjunction with dragline, coal loading, and other dozer operations. This equation is:

The point source dispersion equation was used in conjunction with dragline, coal loading, and other dozer operations. This equation is:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(Eq. 14)}$$

where Q = point source strength, g/s

σ_y = the horizontal standard deviation of plume concentration distribution at the downwind distance x for the prevailing atmospheric stability, m

χ, σ_z, u = same as Equation 14

Step 8 Convert Source Strength to an Emission Rate--

The calculated values of q were converted to an emission rate per vehicle (haul roads and scrapers) or per hour. For the per vehicle unit, the q value in g/s-m was divided by the traffic volume during the sampling period. For the per hour unit, the q value was converted to lb/h at normal operating speed. Similarly, point source Q values were converted to emission rates per ton of material handled or per hour.

In summary, upwind-downwind emission rates were calculated using either a point source or line source version of the Gaussian dispersion equation. The point source equation utilized two additional factors to acccount for

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inability to sample on the plume centerline in the horizontal and vertical dimensions. Each sampler produced a separate estimate of emission rate for the test, so eight to 10 values associated with different downwind distances were generated for each test.

IP and FP emission rates could have been calculated by using the procedure described above. However, at any specified point within the plume, the calculated emission rate is directly proportional to measured concentration. Therefore, ratios of measured IP and FP concentrations to TSP concentrations were calculated for each pair of dichotomous and hi-vol samplers. The resulting fractions were multiplied by the calculated TSP emission rate for the corresponding point in the plume to get IP and FP emission rates.

If particle deposition is significant over the distance of the downwind sampler array, apparent emission rates should decrease with distance from the source. Therefore, upwind-downwind sampling provided an implicit measure of the rate of deposition. In addition, the possible decrease in apparent emission rate with distance meant that the eight to 10 different values for a test could not simply be averaged to obtain a single emission rate for the test. The procedure for combining the values is explained in a following subsection.

Balloon Sampling

This calculation procedure combines concepts used in quasi-stack and exposure profiling sampling. However, it is less accurate than either of these two methods because the sampling equipment does not operate at isokinetic flow rates.

The balloon samplers were preset to a flow rate that was isokinetic at a wind speed of 5 mph. Since wind speed only approached this speed in two of the 18 tests, the sampling rates were normally super-isokinetic. The other two types of equipment in the array, hi-vols and dichotomous samplers, sample at a relatively constant air flow. In spite of this limitation, it was judged that a calculation involving integration of concentrations would yield better results than could be obtained by using a dispersion equation.

Step 1 Plot Concentration Data in Horizontal and Vertical Dimensions--

Concentration data from the ground-based hi-vols and balloon-suspended samplers yield a concentration profile of the plume in both the horizontal and vertical directions. By combining these profiles with visual observations and photographs, it was possible to determine the plume boundaries. Conceptually, the next step was to approximate the volume of air that passed the sampling array by multiplying the product of wind speed and sampling duration by the cross-sectional area of the plume. The concept is similar to the procedures used in the quasi-stack calculations. Quasi-stack calculations are discussed in the next subsection.

The calculation procedure is essentially a graphical integration technique. Concentrations measured by the ground-level hi-vols (2.5 m height) were plotted against their horizontal spacing. Bu using visual observations, photographs taken in the field, and the curve itself, the profile was extrapolated to zero concentration at both edges of the plume. The resulting curve was assumed to represent the concentration profile at ground level and was graphically integrated. This concept is demonstrated in Figure 5-2.

Step 2 Estimate the Volume Formed by the Two Profiles--

The balloon samplers were suspended at five specific heights of 2.5, 7.6, 15.2, 22.9, and 30.5 m. Since concentrations measured by these samplers were not directly comparable to those from hi-vols, concentrations at the four heights about 2.5 m were expressed as ratios of the 2.5 m concentration. The resulting curve of relative concentration versus height was extrapolated to a height of zero concentration, as shown in Figure 5-3. The next step was to multiply each of the ratios by the area under the ground level concentration profile. This produced an approximation of the relative integrated concentration at each of the five heights. By using a trapezoidal approximation technique, an estimate of the volume formed by the two profiles was obtained.

Step 3 Calculate the TSP Emission Rate--

The final emission rate calculation was made with the following equation:

$$E = 60\ V(u)t \qquad \text{(Eq. 15)}$$

where E = total emissions from blast, mg

V = volume under the two profiles, mg/m

u = wind speed, m/s

t = sampling duration, min

The final result was then converted to lb/blast. This value was recorded as the TSP emission rate.

The next step was to calculate IP and FP emision rates. The unadjusted IP and FP concentrations for each dichot were expressed as fractions of their associated hi-vol concentrations. Then, the averages of the five unadjusted IP fractions and the five FP fractions were calculated and the 50 percent cut point for IP was adjusted to account for the inlet's dependence on wind speed. A more detailed discussion of the correction for wind speed is presented in a later subsection. The resulting fractions were multiplied by the TSP emission rate and the results reported as IP and FP emission rates.

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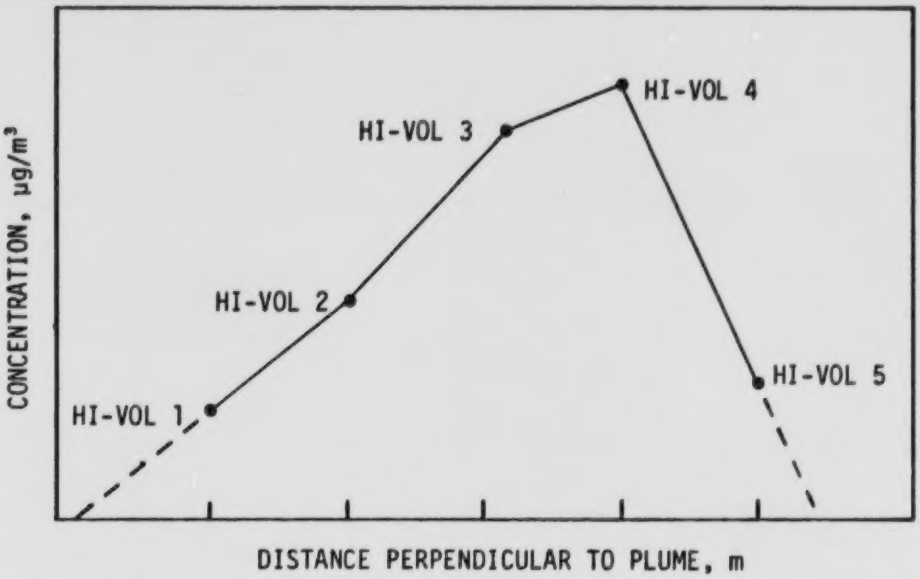

Figure 5-2. Example ground-level concentration profile.

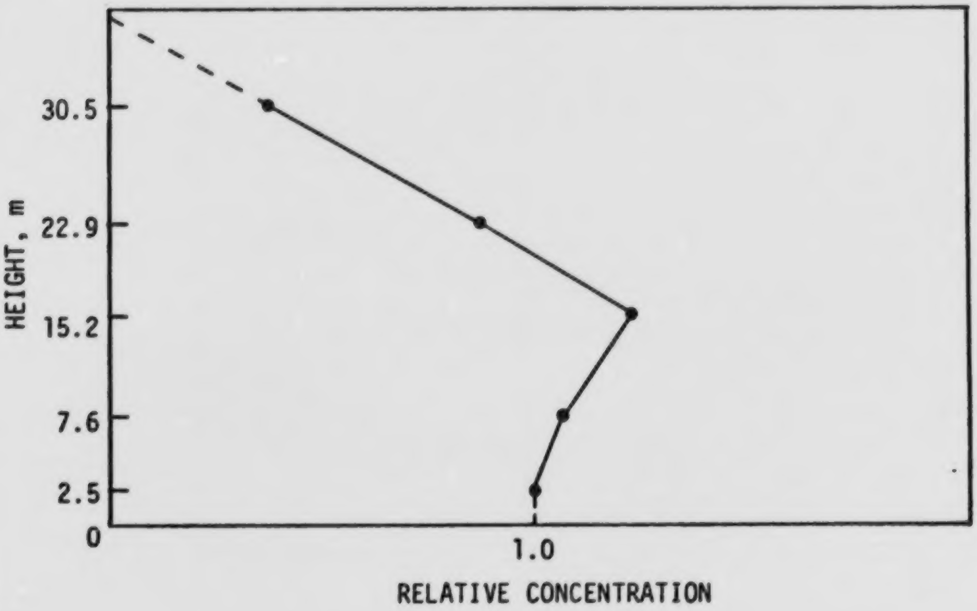

Figure 5-3. Example vertical concentration profile.

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The procedure outlined above incorporates a critical assumption concerning particle size distribution. Due to a lack of particle size data at each height, the assumption has been made that the fractions of the concentration less than 15 and 2.5 µm are the same throughout the plume as they are at 2.5 m height. Since particle size distribution measured at ground level was applied to the entire plume, the reported IP and FP emission rates are probably underestimates.

Wind Tunnel

To calculate emission rates from wind tunnel data, a conservation of mass approach is used. The quantity of airborne particulate generated by wind erosion of the test surface equals the quantity leaving the tunnel minus the quantity (background) entering the tunnel. Calculation steps are described below.

Step 1 Calculate Weights of Collected Sample--

The samples are all collected on filters. Weights are determined by subtracting tare weights from final filter weights.

Step 2 Calculate Particulate Concentrations--

The concentration of particulate matter measured by a sampler, expressed in units of micrograms per cubic meter ($\mu g/m^3$), is given by the following equation:

$$C = 3.53 \times 10^4 \frac{m}{Q_s t} \qquad \text{(Eq. 16)}$$

where C = particulate concentration, $\mu g/m^3$

m = particulate sample weight, mg

Q_s = sampler flow rate, ACFM

t = duration of sampling, min

The coefficient in Equation 16 is simply a conversion factor.

The specific particulate matter concentrations determined from the various sampler catches are as follows:

TP - Cyclone/cascade impactor: cyclone catch + substrate catches + backup filter catch

TSP - Hi-Vol sampler: filter catch

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To be consistent with the National Ambient Air Quality Standard for TSP, concentrations should be expressed at standard conditions (25° and 29.92 in. of Hg.).

Tunnel inlet (background) concentrations of TP or any of the respective particulate size fractions are subtracted from corresponding tunnel exit concentrations to produce "net" concentrations attributable to the tested source. The tunnel inlet TP concentration is preferably obtained with an isokinetic sampler, but should be represented well by the TSP concentration measured by the modified hi-vol, if there are no nearby sources that would have a coarse particle impact on the tunnel inlet air.

Step 3 Calculate Tunnel Volume Flow Rate--

During testing, the wind speed profile along the vertical bisector of the tunnel working section is measured with a standard pitot tube and included manometer, using the following equation:

$$u(z) = 6.51 \frac{H(z)\ T}{P} \qquad \text{(Eq. 17)}$$

where $u(z)$ = wind speed, m/s

$H(z)$ = manometer reading, in. H_2O

z = height above test surface, cm

T = tunnel air temperature, °K

P = tunnel air pressure, in. Hg

The values for T and P are equivalent to ambient conditions.

A pitot tube and inclined manometer are also used to measure the centerline wind speed in the sampling duct, at the point where the sampling probe is installed. Because the ratio of the centerline wind speed in the sampling duct to the centerline wind speed in the test section is independent of flow rate, it can be used to determine isokinetic sampling conditions for any flow rate in the tunnel.

The velocity profile near the test surface (tunnel floor) and the walls of the tunnel is found to follow a logarithmic distribution (Gillette 1978):

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_o} \qquad \text{(Eq. 18)}$$

where u^* = friction velocity, cm/s

z_o = roughness height, cm

The roughness height of the test surface is determined by extrapolation of the velocity profile near the surface to $z=0$. The roughness height for the plexiglas walls and ceiling of the tunnel is $6 \times 10^{-}$ cm. These velocity profiles are integrated over the cross-sectional area of the tunnel (30.5 cm x 30.5 cm) to yield the volumetric flow rate through the tunnel for a particular set of test conditions.

Step 4 Calculate Isokinetic Flow Ratio--

The isokinetic flow ratio (IFR) is the ratio of the sampler intake air speed to the wind speed approaching the sampler. It is given by:

$$\mathrm{IFR} = \frac{Q_s}{aU_s} \qquad \text{(Eq. 19)}$$

where Q_s = sampler flow rate, ACFM

a = intake area of sampler, ft^2

U_s = wind speed approaching the sampler, fpm

IFR is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias.

Step 5 Calculate Downstream Particle Size Distribution--

The downstream particle size distribution of source-contributed particulate matter may be calculated from the net TP concentration and the net concentrations measured by the cyclone and by each cascade impactor stage. The 50 percent cutoff diameters for the cyclone precollector and each impaction stage must be adjusted to the sampler flow rate. Corrections for coarse particle bounce are recommended.

Because the particle size cut point of the cyclone is about 11 um, the determination of suspended particulate (SP, less than 30 um) concentration and IP concentration requires extrapolation of the particle size distribution to obtain the percentage of TP that consists of SP (or IP). A lognormal size distribution is used for this extrapolation.

Step 6 Calculate Particulate Emission Rates--

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The emission rate for airborne particulate of a given particle size range generated by wind erosion of the test surface is given by:

$$e = \frac{C_n Q_t}{A} \qquad \text{(Eq. 20)}$$

where e = particulate emission rate, $g/m^2\text{-}s$

C_n = net particulate concentration, g/m^3)

Q_t = tunnel flow rate, m^3/s

A = exposed test area = $0.918m^2$

Step 7 Calculate Erosion Potential--

If the emission rate is found to decay significantly (by more than about 20 percent) during back-to-back tests of a given surface at the same wind speed, due to the presence of non-erodible elements on the surface, then an additional calculation step must be performed to determine the erosion potential of the test surface. The erosion potential is the total quantity of erodible particles, in any specified particle size range, present on the surface (per unit area) prior to the onset of erosion. Because wind erosion is an avalanching process, it is reasonable to assume that the loss rate from the surface if proportional to the amount of erodible material remaining;

$$M_t = M_o e^{-kt} \qquad \text{(Eq. 21)}$$

where M_t = quantity of erodible material present on the surface at any time, g/m^2

M_o = erosion potential, i.e., quantity of erodible material present on the surface before the onset of erosion, g/m^2

k = constant, s^{-1}

t = cumulative erosion time, s

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Consistent with Equation 21, the erosion potential may be calculated from the measured losses from the test surface to two erosion times:

$$\frac{\ln\left(\frac{M_o - L_1}{M_o}\right)}{\ln\left(\frac{M_o - L_2}{M_o}\right)} = \frac{t_1}{t_2} \qquad \text{(Eq. 22)}$$

where L_1 = measured loss during time period 0 to t_1, g/m^2

L_2 = measured loss during time period 0 to t_2, g/m^2

The loss may be back-calculated as the product of the emission rate from Equation 20 and the cumulative erosion time.

Quasi-Stack

The source strengths of the drill tests are determined by multiplying the average particulate concentration in the sampled volume of air by the total volume of air that passed through the enclosure during the test. For this calculation procedure, the air passing through the enclosure is assumed to contain all of the particulate emitted by the source. This calculation can be expressed as:

$$E = \chi V \qquad \text{(Eq. 23)}$$

where E = source strength, g

χ = concentration, g/m^3

V = total volume, m^3

Step 1 Determine Particle Size Fractions--

As described in Section 3, isokinetic samplers were used to obtain total concentration data for the particulate emissions passing through the enclosure. Originally, these data were to be related to particle size, based on the results of microscopic analyses. However, the inconsistent results obtained from the comparability tests precluded the use of this technique for particle sizing. Consequently, the total concentration data were divided into suspended and settleable fractions. The filter fraction of the concentration was assumed to be suspended particulate and the remainder was assumed to be settleable particulate.

Step 2 Determine Concentration for Each Sampler--

Rather than traverse the enclosure, as is done in conventional source testing, four separate profiler samplers were used during each test. These samplers were spaced at regular intervals along the horizontal centerline of the enclosure. Each sampler was set to approximate isokinetic sampling rate. This rate was determined from the wind velocity measured at each sampler with a hot-wire anemometer. The wind velocity was checked at each sampler every 2 to 3 minutes and the sampling rates were adjusted as necessary.

Step 3 Calculate volume of Air Sampled by Each Profiler--

In order to simplify the calculation of source strength, it was assumed that the concentration and wind velocity measured at each sampler were representative of one-fourth the cross-sectional area of the enclosure. Thus, the total volume of air associated with each profiler concentration was calculated as follows:

$$V_i = (u_i)\ (a/4)(t) \qquad \text{(Eq. 24)}$$

where V_i = total volume of air associated with sampler i, m^3

u_i = mean velocity measured at sampler i, m/min

a = cross-sectional area of enclosure, m^2

t = sampling duration, min

Step 4 Calculate the Total Emissions as Sum of Four Partial Emission Rates--

Separate source strengths, E, are calculated for the total concentration and the fraction captured on the filter. The equation is:

$$E = \sum_{i=1}^{4} V_i\ x_i \qquad \text{(Eq. 25)}$$

These source strengths, in grams, were converted to pounds per hole drilled and are reported in Section 11.

PARTICLE SIZE CORRECTIONS

Several different size fraction measurements require a mathematical calculation to correct for some deficiency in the sampling equipment from ideal size separation. Three of the calculation procedures are described here:

Correction of dichotomous samples to 15 μm values

Conversion of physical diameters measured microscopically to equivalent aerodynamic diameters

Correction of cascade impactor data to account for particle bounce-through.

Correction of Dichotomous Data

Recent research indicates that the collection efficiency of the dichotomous sampler inlet is dependent on wind speed (Wedding 1980). As shown in Figure 5-4, the 50 percent cut point that is nominally 15 μm actually varies from 10 to 22 μm over the range of wind speeds tested.

The procedure developed in the present study to correct dichot concentrations to a 15 um cut point was to:

1. Determine the average wind speed for each test period.
2. Estimate the actual cut point for the sample from Figure 5-4.
3. Calculate net concentrations for each stage by substracting upwind dichot concentrations.
4. Calculate the total concentration less than the estimated cut point diameter by summing the net concentrations on the two stages.
5. Adjust the fine fraction (<2.5 μm) concentration by multiplying by 1.11 to account for fine particles that remain in the portion of the air stream that carries the coarse fraction particles.
6. Calculate the ratio of fine fraction to net TSP concentration and the ratio of total net dichot concentration to net TSP concentration.
7. Plot (on log-probability paper) two data points on a graph of particle size versus fraction of TSP concentration. The two points are the fraction less than 2.5 μm and the fraction less than the cut point determined in step 2.
8. Draw a straight line through the two points and interpolate or extrapolate the fraction less than 15 μm. (Steps 7 and 8 are a graphical solution that may be replaced by a calculator program that can perform the linear interpolation or extrapolation with greater precision.)

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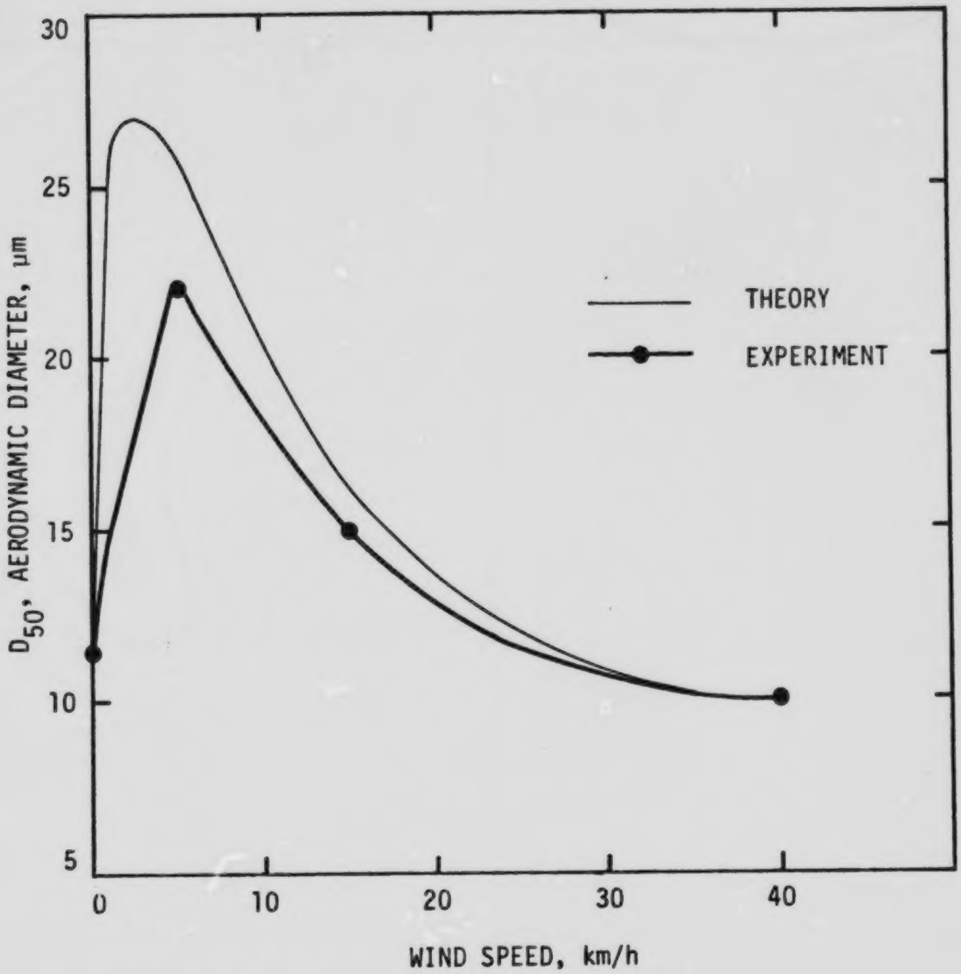

Figure 5-4. Plot of the 50 percent cut point of the inlet versus wind speed.

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9. Calculate the net concentration less than 15 µm from this fraction and the known net TSP concentration.

A relatively small error is involved in the assumption of a log linear curve between the two points because the 15 um point is so near the point for the actual upper limit particle size. The largest uncertainty in applying this correction is probably the accuracy of the research data in Figure 5-4.

Conversion of Microscopy Data to Aerodynamic Diameters

Three calculation procedures for converting physical particle diameters into equivalent aerodynamic diameters were found in the literature (Hesketh 1977; Stockham 1977; and Mercer 1973). One of these was utilized in calculations in a recent EPA publication, so this procedure was adopted for the present project (U.S. Environmental Protection Agency 1978b). The equation relating the two measurements of particle size is:

$$d_a = d\sqrt{\frac{\rho C}{C_a}} \qquad \text{(Eq. 26)}$$

where d_a = particle aerodynamic diameter, µm

d = particle physical diameter, µm

ρ = particle density

C = Cunningham factor

$= 1 + 0.000621\ T/d$

T = temperature, °K

C_a = Cunningham correction for d_a

This equation requires a trial-and-error solution because C_a is a function of d. The multiple iterations can be performed by a computer or calculator program (U.S. Environmental Protection Agency 1978b).

In practice, C_a is approximately equal to C so the aerodynamic diameter (d_a) is approximately the physical diamter (d) times p. An average particle density of 2.5 was assumed with the microscopy data from this study, thus yielding conversion factors of about 1.58. It is questionable whether the trial-and-error calculation of C_a in Equation 26 is warranted when density values are assumed.

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Correction of Cascade Impactor Data

To correct for particle bounce-through, MRI has developed a procedure for adjusting the size distribution data obtained from its cascade impactors, which are equipped with cyclone precollectors. The true size distribution (after correction) is assumed to be lognormal as defined by two data points: the corrected fraction of particulate penetrating the final impaction stage (less than 0.7 µm) and the fraction of particulate caught by the cyclone (greater than about 10 µm). The weight of material on the backup stage was replaced (corrected) by the average of weights caught on the two preceding impaction stages if the backup stage weight was higher than this average.

Because the particulate matter collected downwind of a fugitive dust source is produced primarily by a uniform physical generation mechanism, it was judged reasonable to assume that the size distribution of airborne particulate smaller than 30 µm is lognormal. This in fact is suggested by the uncorrected particle size distributions previously measured by MRI.

The isokinetic sampling system for the portable wind tunnel utilizes the same type of cyclone precollector and cascade impactor. An identical particle bounce-through correction procedure was used with this system.

COMBINING RESULTS OF INDIVIDUAL SAMPLES AND TESTS

Combining Samples

In the quasi-stack and exposure profiling sampling methods, multiple samples were taken across the plume and the measurements were combined in the calculations to produce a single estimate of emission rate for each test. However, in the upwind-downwind method, several (eight to 10) independent estimates of emission rate were generated for a single sampling period. These independent estimates were made at different downwind distances and therefore had differing amounts of deposition associated with them.

The procedure for combining upwind-downwind samples was based on comparison of emission rates as a function of distance. If apparent emission rates consistently decreased with distance (not more than two values out of progression for a test), the average from the front row samplers was taken as the initial emission rate and deposition at succeeding distances was reported as a percent of the initial emission rate. If apparent emission rates did not have a consistent trend or increased with distance, then all values were averaged to get an emission rate for the test and deposition was reported as negligible. Since deposition cannot be a negative value, increases in apparent emission rates with distance were attributed to data scatter, non-Gaussian plume dispersion, or inability to accurately locate the plume centerline (for point sources).

The amount of deposition from the front row to the back row of samplers is related to the distance of these samplers from the source, i.e., if the front samplers are at the edge of the source and back row is 100 m downwind (this was the standard set-up for line sources), a detectable reduction in apparent emission rates should result. However, if the front row is 60 m from the source and back row is 100 m further downwind (typical set-up for point sources due to safety considerations), the reduction in apparent emission rates with distance is likely to be less than the average difference due to data scatter.

These dual methods of obtaining a single estimate of emission rate for each test introduce an upward bias into the data; high levels on the front row in general lead to their retention as the final values, while low levels in general lead to averaging with higher emission rates from subsequent rows. This bias is thought to be less than the errors that would result in applying either of these methods universally for the different deposition situations described above. It should also be noted that other types of deposition measurements are possible.

Any single estimate more than two standard deviations away from the average of the remaining samples was considered an outlier and not included in calculating the average emission rate.

Combining Tests

Emission rates for three particle size ranges were reported for all tests, along with data on the conditions under which the tests were taken. These data were first subjected to multiple linear regression (MLR) analysis, as described below. Of the three size ranges, only the TSP and IP data were used in the MLR analysis. This analysis identified significant correction parameters for each source.

Next, adjusted emission rates were calculated for each test with the significant correction parameters. From this data set, average emission rates (base emission factors) and confidence intervals were calculated. The emission factor equation is this average emission rate times the correction factors determined from the MLR analysis.

PROCEDURE FOR DEVELOPMENT OF CORRECTION FACTORS

The method used to evaluate independent variables for possible use as correction factors was stepwise MLR. It was available as a compute program as part of the Statistical Package for the Social Sciences (SPSS). The MLR program outputs of interest in evaluating the data sets for each source were the multiple regression coefficient, significance of the variable, and reduction in relative standard deviation due to each variable. The stepwise MLR technique is described in moderate detail in Appendix A. Further information on it can be found in the following references:

Statistical Methods, Fourth Edition (Snedecor 1946); Applied Regression Analysis (Draper 1965); and SPSS, Second Edition (Nie 1975).

Because of the high relative standard deviations $(s/\overline{x})$ for the data sets and the desire to have correction factors in the emission factor equations multiplicative rather than additive, all independent and dependent variable data were transformed to natural logarithms before being entered in the MLR program.

The stepwise regression program first selected the potential correction factor that was the best predictor of TSP emission rate, changed the dependent variable values to reflect the impact of this independent variable, then repeated this process with remaining potential correction factors until all had been used in the MLR equation or until no improvements in the predictive equation was obtained by adding another variable. Not all variables included in the MLR equation were necessarily selected as correction factors.

A detailed description of correction factor development procedures is given in Section 13 of Volume II.

SECTION 6

RESULTS OF SIMULTANEOUS EXPOSURE PROFILING AND UPWIND-DOWNWIND SAMPLING

The exposure profiling and upwind-downwind samplers were run on a common source for several tests so that simultaneous measurements by these methods could be compared. This complex undertaking was essential to establish that the methods were yielding similar results. The simultaneous sampling, called the comparability study, was performed before any of the other testing so that any major discrepancies could be resolved or the study design reevaluated prior to sampling at the second and third mines.

The original intent was to prepare a technical report on the results of the comparability study and any recommended sampling modifications for distribution between the first and second mine visits. However, a series of changes in the method of calculating the suspended particulate fraction of the total profiler catch and the temporary nonavailability of an EPA-recommended computer program for particle size interpolation prevented the exposure profiling values from being determined. Preliminary calculations for six of the 10 tests, presented at a September 13, 1979 meeting of the technical review group after completing the last comparability test on August 9, indicated good agreement between the two methods:

> The average ratio for 14 pairs of simultaneous measurements was reported to be 0.92, with only two of the paired values differing by more than a factor of 2.0.

Therefore, sampling was conducted as specified in the study design report at the other two mines. By the time the calculations for suspended particulate from profiler tests were finalized, the need for a separate comparability study report had passed.

DESCRIPTION OF COMPARABILTY STUDY

The two sources selected for testing in the comparability study were haul roads and scrapers. They are ground-level moving point sources (line sources) that emit from relatively fixed boundaries, so the alternative sampling methods are both appropriate and the extensive sampling array could be located without fear of the source changing locations. Also, haul roads and scrapers were suspected to be two of the largest fugitive dust emission sources at most surface coal mines.

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Five tests of each source were conducted over a 15-day period. One additional haul road test was attempted but aborted because of wind direction reversal shortly after the beginning of the test. The individual tests were of about one hour duration. All five tests of each source were performed at a single site; only two sites and one mine were involved in the comparability study.

Profiling towers were placed at three distances from the source--5, 20, and 50 m--in order to measure the decrease in particulate flux with distance, and indirectly the deposition rate. The relatively large distances of the back profiler from the source created one problem: these two profilers had to be significantly taller than the first tower because the vertical extent of the plume expands with distance from the source. The towers were fabricated to be 9 and 12 m high, respectively, for the 20 and 50 m setbacks.

Hi-vols and dichotomous samplers for the upwind-downwind configuration were located at the same three downwind distances as the profiling towers. Two samplers of each type were placed at these distances. In addition, two hi-vols were located at 100 m downwind of the source.

Duplicate dustfall buckets were placed at the 5, 20, and 50 m distances to measure deposition rates directly, for comparison with the calculated plume mass depletion rates from the profiler and upwind-downwind samplers. Some sampling equipment was also set out to obtain independent particle size distribution measurements. Cascade impactors were placed at two heights at 5 m setback and at one height at 20 m. Millipore filters for microscopic examination were exposed briefly during each sampling period at five different heights (corresponding to profiler sampling head heights) at the 20 m distance.

Upwind samplers consisted of three hi-vols and a dichotomous sampler, all located 20 m from the upwind edge of the source. Two of these were operated by PEDCo as part of the upwind downwind array, and the other two (hi-vols at 1.5 and 2.5 m height) were operated by MRI as the background samplers at the 5 m downwind distance as parts of their separate arrays, but which also served as quality assurance checks for the sampling and equipment.

Finally, wind speed and direction were continuously recorded during the tests by separate instruments operated by PEDCo and MRI. Profile samplers on each tower were kept at isokinetic flow rates by frequency monitoring hot-wire anemometers at the heights of each of the samplers and adjusting flows to match measured wind speeds. Therefore, wind speeds from five different locations in the sampling array and two wind direction charts were available for comparison.

The sampling configuration used in the comparability study is shown schematically in Figure 6-1. These sampling periods involved much extra equipment, so it was not feasible to use this configuration throughout the project.

RESULTS OF COMPARABILITY STUDY

Particle Size Data

Particle size data were generated by three different methods in the comparability study: dichotomous sampler, cascade impactor and microscopy. These three methods all have some shortcomings; corrections to the data were required in all three cases. The cut pount for the coarse stage of the dichotomous sampler was adjusted to eliminate the wind speed error of the inlet design. The backup filter weight of the cascade impactor was reduced to correct for particle bounce-through; this weight reduction averaged 4.2 percent of the total particulate sample for the ten comparability tests shown in Table 6-1. Physical particule sizes measured under the microscope were converted to equivalent aerodynamic diameters for comparison with the other size data. The procedures for these corrections were described in Section 5.

The particle size data for collocated samplers are presented in Table 6-1. For better visual comparison, the size distributions are also shown graphically in Figures 6-2 and 6-3. In order to reduce the curves on each graph to a manageable number, the duplicate samples taken by the same method at each distance (see Tabel 6-1) have been averaged to create a single curve. All of the dichot and impactor curves are straight lines because they are based on two data points and an assumption of lognormal distribution of particles by weight.

Microscopy produced the widest variations between samples--some showed that less than 10 percent of the particles were sub-30 µm and others showed all particles in the sample to be less than 15 µm. It was concluded that the relatively small number of particles counted manually on each filter (300 to 500) precluded the samples from being representative of the actual size distribution. This is particularly evident when the number of large particles counted is considered. Each particle of 40 µm diameter observed has 64,000 times the mass of a 1 µm particle and 64 times the mass of a 10 µm particle. Therefore, if two particles larger than 40 µm are found in the fields selected, this could result in 30 percent by weight being in that size range; whereas, a sample with one particle larger than 40 µm would have only about 17 percent of its weight in that size range. Thus, one extra large particle shifts the entire distribution by 13 percent in this example.

This evaluation is not an indictment of optical microscopy as a particulate assessment technique. In cases where there are different

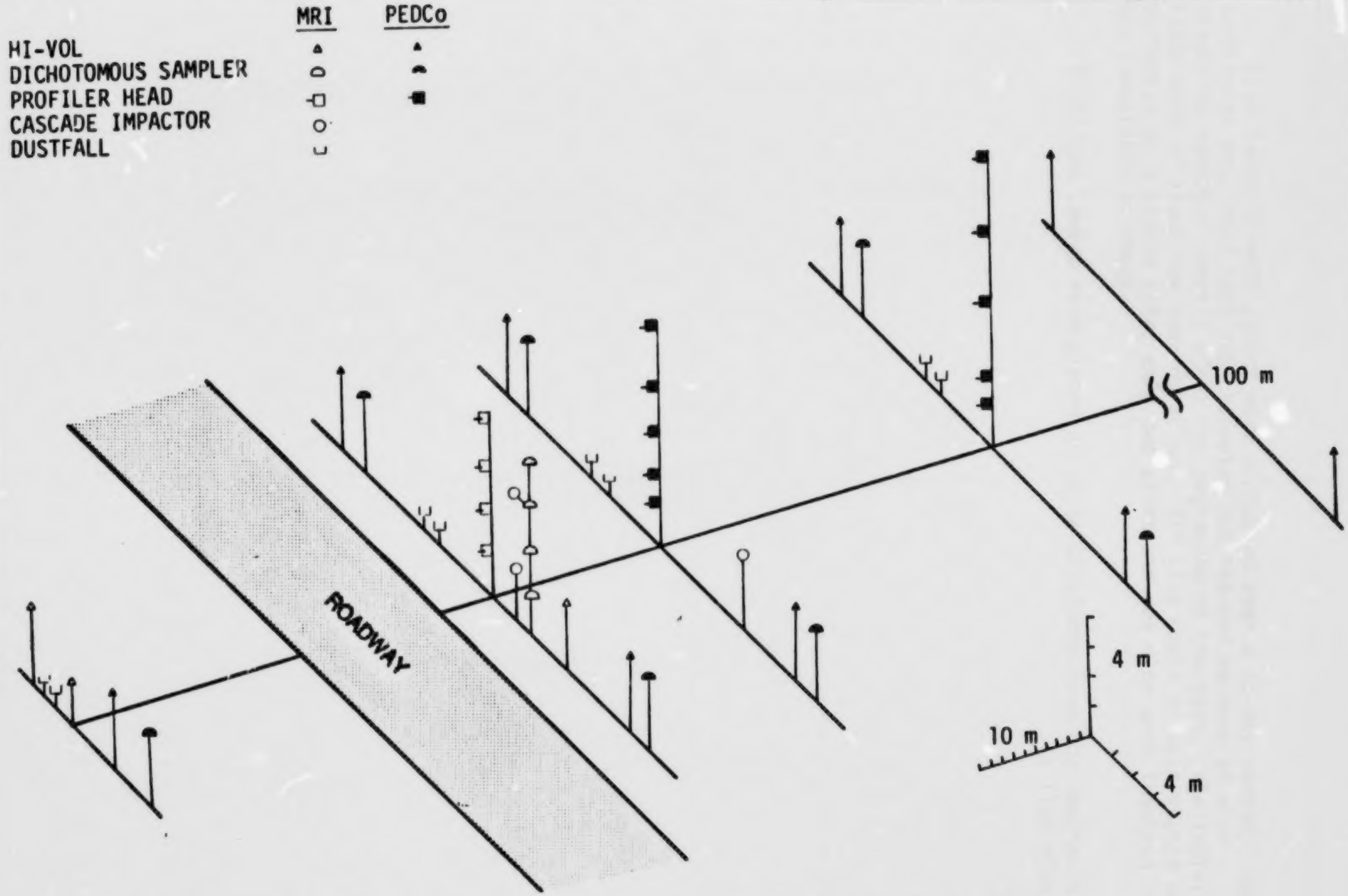
MRI
PEDCo
HI-VOL
DICHOTOMOUS SAMPLER
PROFILER HEAD
CASCADE IMPACTOR
DUSTFALL
ROADWAY
100 m
4 m
10 m
4 m

Figure 6-1. Sampling configuration for comparability studies.

TABLE 6-1. COMPARISON OF PARTICLE SIZE DATA OBTAINED BY DIFFERENT TECHNIQUES

Test	Aero-dynamic size μm	Cumulative percent smaller than stated size									
		At 5 m dist				At 20 m dichot, 2.5 m ht				At 50 m, 2.5 m ht	
		Dichot		Impactor		Dichot		Impactor	Micro-scopy	Dichot	
		3.0 m	6.0 m	1.5 m	4.5 m	Left	Right			Left	Right
J1	2.5	0.5	1.3	2.2	2.7	0.6	0.6	7.2	a	a	a
	5.0	2.1	3.2	4.2	5.4	3.2	4.0	12.3	a	a	a
	10.0	6.3	7.3	7.4	9.8	11.9	16.0	19.7	a	a	a
	15.0	11.0	11.0	10.0[b]	13.5[b]	21.4	29.1	25.1[b]	a	a	a
	20.0	15.5	14.4			30.2	40.7		a	a	a
	30.0	23.7	20.3			44.9	67.8		a	a	a
J2	2.5	1.0	1.2	2.1	19.9	0.8	0.6	1.3	a	4.4	2.8
	5.0	1.6	3.3	4.3	35.7	2.1	2.8	2.6	a	8.2	5.5
	10.0	2.5	7.8	8.2	54.3	5.0	9.6	4.9	a	14.1	10.0
	15.0	3.3	12.1	11.5[b]	65.1[b]	7.7	17.1	6.8[b]	a	18.7	13.6
	20.0	3.9	16.0			10.2	24.2		a	22.4	16.6
	30.0	5.0	22.7			14.8	36.4		a	28.3	21.5
J3	2.5	0.7	5.6	5.7	4.6	0.9	0.7	4.7	9.6[c]	2.0	1.6
	5.0	2.3	11.2	11.2	9.1	3.4	4.0	8.6	21.3	5.7	4.9
	10.0	6.4	20.1	19.6	16.3	10.1	15.0	14.6	33.4	13.2	12.3
	15.0	10.6	26.8	26.1[b]	21.8[b]	17.0	26.8	19.2[b]	44.9	19.9	19.1
	20.0	14.6	32.1			23.3	37.3		68.8	25.8	25.2
	30.0	21.8	40.3			34.2	53.2		100.0	35.4	35.1
J4	2.5	0.4	1.5	2.7	4.4	2.2	2.2	6.2	<0.1[c]	3.7	3.7
	5.0	1.3	3.2	4.9	8.2	4.6	5.3	11.5	0.2	7.8	7.4
	10.0	3.7	6.3	8.4	14.1	8.6	11.1	19.2	0.7	14.6	13.2
	15.0	6.1	7.0	11.2[b]	18.7[b]	12.0	16.1	24.9[b]	2.0	20.1	17.9
	20.0	8.5	11.4			14.8	20.5		4.4	24.7	21.7
	30.0	13.0	15.4			19.7	27.6		8.8	31.9	27.9
J5	2.5	1.8	2.5	6.5	5.5	2.7	3.1	6.6	2.3[c]	7.8	7.6
	5.0	4.3	4.6	11.6	10.0	4.8	7.4	11.9	11.6	13.8	13.3
	10.0	9.1	7.8	19.1	16.7	8.0	15.2	19.7	44.9	22.3	21.4
	15.0	13.2	10.4	24.6[b]	21.8[b]	10.5	21.7	25.4[b]	100.0	28.3	27.2
	20.0	16.9	12.6			12.5	27.1			33.1	31.7
	30.0	23.0	16.1			15.9	35.8			40.3	38.6
J9	2.5	0.9	2.7	2.3	2.7	1.4	1.6	3.2	2.6[c]	1.8	1.8
	5.0	3.0	7.1	4.9	5.3	5.3	8.7	6.7	12.9	6.3	7.0
	10.0	8.5	15.6	9.5	9.5	14.8	28.4	12.4	54.4	16.8	19.7
	15.0	13.9	22.9	13.4[b]	12.8[b]	23.9	45.5	16.9[b]	69.7	26.5	31.2

(continued)

TABLE 6-1 (continued).

Test	Aerodynamic size µm	Cumulative percent smaller than stated size									
		At 5 m dist				At 20 m dichot, 2.5 m ht				At 50 m, 2.5 m ht	
		Dichot		Impactor		Dichot		Impactor	Microscopy	Dichot	
		3.0 m	6.0 m	1.5 m	4.5 m	Left	Right			Left	Right
	20.0	19.1	29.0			31.9	58.0		87.6	34.7	40.8
	30.0	28.0	38.8			44.7	74.6		100.0	47.5	54.7
J10	2.5	1.2	3.5	7.3	4.7	3.4	1.7	9.8	<0.1[c]	4.0	2.0
	5.0	4.1	11.2	13.0	9.3	14.1	9.9	17.0	0.3	10.0	5.9
	10.0	11.2	27.0	21.3	16.7	37.1	32.3	27.0	1.2	20.9	14.0
	15.0	18.0	39.8	27.3[b]	22.4[b]	53.9	50.6	33.9[b]	4.2	29.6	21.4
	20.0	24.3	49.6			65.8	64.1		6.3	36.7	27.7
	30.0	34.7	63.4			80.1	80.1		9.4	47.4	37.9
J12	2.5	1.5	6.8	5.4	13.5	3.5	2.8	11.5	0.8[c]	3.6	4.5
	5.0	4.5	14.1	10.2	22.7	10.0	7.7	19.6	19.5	8.9	11.8
	10.0	11.1	25.4	17.7	34.7	22.6	17.4	30.5	88.7	18.4	24.8
	15.0	17.3	33.6	23.3[b]	42.6[b]	32.9	25.6	37.8[b]	100.0	26.2	35.0
	20.0	22.8	40.1			41.2	32.5			32.6	43.0
	30.0	31.9	49.6			53.0	43.3			42.5	54.3
J20	2.5	0.5	0.4	3.7	3.9	7.7	5.0	5.8	a	2.5	2.9
	5.0	2.7	2.2	6.7	7.2	15.5	12.5	9.9	a	7.0	9.3
	10.0	10.6	8.9	11.3	12.4	27.2	25.5	16.0	a	15.9	22.6
	15.0	19.6	16.8	14.9[b]	16.4[b]	35.7	35.6	20.5[b]	a	23.6	33.8
	20.0	28.2	24.6			42.2	43.5			30.2	42.8
	30.0	42.7	38.2			51.2	54.4			40.6	55.6
J21	2.5	0.6	0.4	7.7	9.0	2.8	4.5	10.0	a	8.7	5.4
	5.0	2.6	1.4	14.3	16.2	8.3	11.0	18.5	a	17.1	15.2
	10.0	8.3	3.8	23.8	26.4	19.4	22.4	30.5	a	29.4	32.6
	15.0	14.5	6.2	30.6[b]	33.5[b]	28.8	31.3	38.8[b]	a	38.2	45.6
	20.0	20.3	9.1			36.6	38.5			44.7	54.6
	30.0	30.7	14.0			48.5	49.2			53.8	67.5

[a] No data.

[b] Extrapolated from 10 µm and 0.7 µm data.

[c] Extrapolated assuming a lognormal distribution below 5 µm.

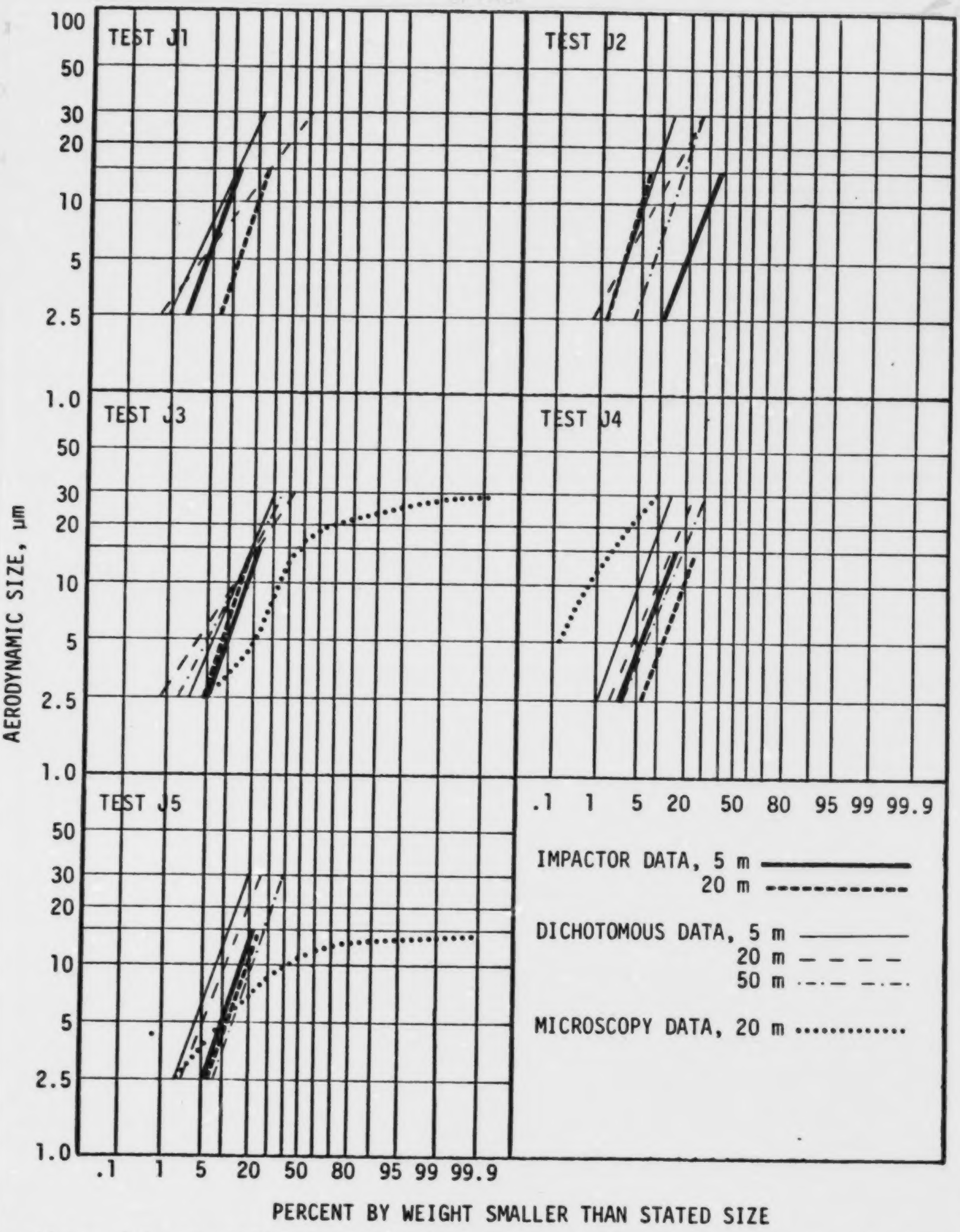

Figure 6-2. Particle size distributions from comparability tests on scrapers.

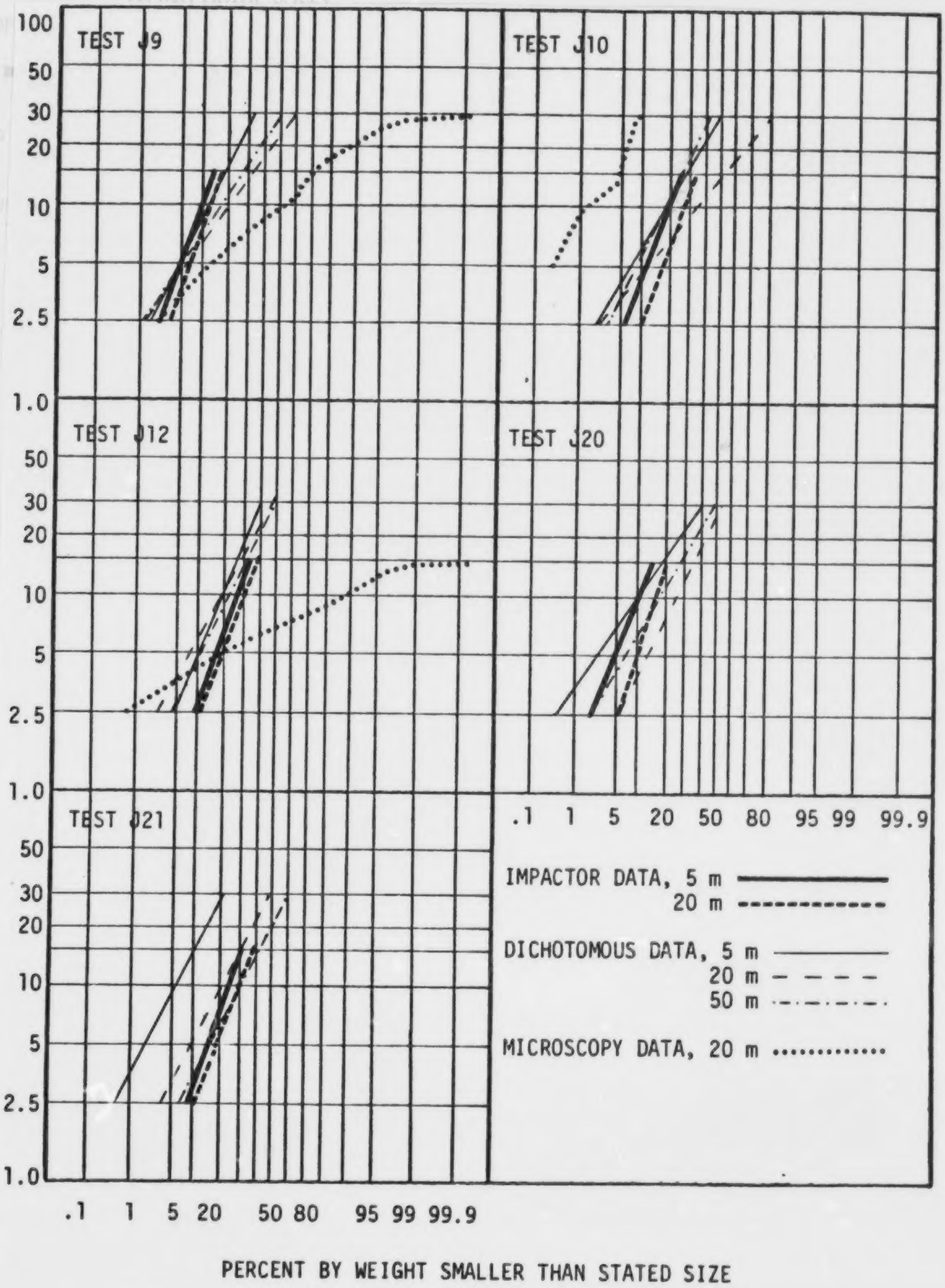

Figure 6-3. Particle size distributions from comparability tests on haul roads.

particle types present and the primary purpose is to semiquantitatively estimate the relative amounts, microscopy is usually the best analytical tool available. However, as a pure particle sizing method, microscopy appears to be inadequate compared to available aerodynamic techniques.

In contrast, the dichotomous samplers and cascade impactors produced fairly consistent size distributions from test to test (as would be expected) and reasonably good agreement between methods. The cascade impactor data always indicated higher percentages of particles less than 2.5 µm, but approached the cumulative percentages of the dichot method for the 10 to 15 um sizes. This may reveal that the corrections to impactor data for particle bounce-through were not large enough.

Data from the dichots at 3 and 6 m heights and the impactors at 1.5 and 4.5 m heights had similar variations in size distribution with height. For both types of samplers, most of the tests (6 out of 10) showed more large particles on the lower sampler, but several tests showed larger particles on the upper sampler. This provides evidence that the plume is still not well formed at the 5 m distance from the source.

Comparison ofsize distributions taken at successive distances from the source revealed that the percentage of small particles increased from 5 m samples to 20 m samples in all but two cases out of 20. This finding is consistent with the premise of fallout of larger particles. However, reduction in mean particle size was not obvious in the comparison of corresponding data from 20 m and 50 m; only half the tests showed a further decrease in average particle size and some actually had larger average particle sizes.

Th dichotomous samplers appeared to give the most reliable results, either by comparing the distributions taken at different distances in the same test or by evaluating the effects of corrections made to the raw data. As indicated in Section 4, handling problems with the dichot filter and light loadings on the fine particle stages prevented this from being a completely satisfactory sizing method for the large numbers of samples generated in the full study. Sampling precision errors resulting from these factors are quantified in the following subsection. These problems are discussed further in Section 12, Volume II.

The ratios of net fine particulate (less than 2.5 µm) and inhalable particulate to net TSP are also sizing measures of interest. These data for collocated samplers in the comparability study are presented in Table 6-2. The average ratio for all the fine particulate (FP) samples was 0.039, indicating a very low percentage of small particles in the plumes. As expected, this ratio incrased with distance from the source due to fallout of larger particles but not of the fine particles. The average ratios at 5, 20, and 50 m downwind were 0.016, 0.042, and 0.062, respectively. Inhalable particulate constituted a much larger fraction of TSP--an average ratio of 0.52. Again, the differential effect of fallout on large particles

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was evident. The average IS/TSP ratios at the three sampling distances were 0.36, 0.48 and 0.73.

Simultaneous Sampling

Samplers located at the same distance from the line sources (but not collocted) showed only fair agreement in their measured concentrations. The average absolute relative difference in the measured TSP values was 17.8 percent; the average (signed) relative difference was 10.6 percent. The average absolute and signed relative differences at the three distances were:

Distance	Av. diff., %	Signed diff., %
5	25.3	17.7
20	13.5	11.5
50	13.7	2.7

Absolute relative difference for each pair is calculated as the absolute difference between values divided by the mean of the two values, expressed as a percent: Absolute rel. diff. = $\frac{|a-b|}{(a+b)/2}$ x100. Signed relative difference employs the same calculations, but the algebraic rather than absolute difference is used.

For IP and FP, the corresponding average absolute relative differences were 25.3 and 29.1 percent. Average signed differences were 8.9 and 17.7 percent, respectively. The IP and FP differences at the three sampling distances were:

	Avg. abs rel. diff, %		Avg. signed rel. diff, %	
Distance	IP	FP	IP	FP
5	19.4	37.9	3.6	26.9
20	36.6	25.7	30.4	10.1
50	19.9	23.6	0.1	16.2

These differences provide an estimate of sampling precision, although they could be attributed partially to actual differences in source strength at various locations along the line source, since the samplers were not collocated. The larger differences in TSP concentrations at the 5 m distance could be due to highly erratic concentrations in the immediate area of plume formation. No explanation was found for the large IP differences at the 20 m distance.

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TABLE 6-2. RATIOS OF NET FINE AND INHALABLE PARTICULATE CONCENTRATIONS TO NET TSP CONCENTRATIONS

Test	Downwind distance, m	Net TSP conc, μg/m³		Ratio of FP (<2.5 μm) to TSP		Ratio of IP (<15 μm) to TSP	
		Left	Right	Left	Right	Left	Right
Scrapers							
J1	5	3,389	4,377	0.01	<0.01	0.34	0.23
	20	2,573	3,081	0.01	<0.01	0.28	0.32
	50	1,032	1,264	0.01	0.01	0.56	0.29
J2	5	10,402	14,174	<0.01	0.01	0.22	0.20
	20	4,877	4,997	0.01	0.01	0.13	0.31
	50	947	1,107	0.13	0.06	0.50	0.37
J3	5	16,884	21,347	0.02	0.01	0.48	0.33
	20	5,331	-	0.01	-	0.24	-
	50	1,542	1,656	0.02	0.01	0.39	0.34
J4	5	2,267	2,529	0.02	0.01	0.20	0.17
	20	1,107	1,278	0.01	0.01	0.14	0.19
	50	484	462	0.03	0.03	0.35	0.30
J5	5	2,894	5,496	0.02	0.01	0.42	0.22
	20	1,767	-	0.01	-	0.07	-
	50	417	250	0.03	0.04	0.25	0.40
Haul roads							
J9	5	4,736	3,554	0.01	0.01	0.54	0.46
	20	1,942	2,957	0.02	0.02	0.52	0.73
	50	1,280	1,033	0.01	0.01	0.30	0.49
J10	5	4,579	3,920	0.02	0.01	0.57	0.40
	20	2,210	1,946	0.04	<0.01	0.85	0.88
	50	470	485	0.26	0.06	1.92[a]	1.11[a]
J12	5	1,757	1,772	0.03	0.01	0.21	0.15
	20	1,142	1,188	0.04	0.03	0.35	0.21
	50	432	378	-	0.05	-	0.17
J20	5	1,911	2,883	0.01	0	0.75	0.45
	20	902	1,051	0.28	0.14	1.42[b]	1.26[b]
	50	361	361	0.09	0.13	1.93[b]	3.20[b]

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TABLE 6-2 (continued).

Test	Downwind distance, m	Net TSP conc, μg/m³		Ratio of FP (<2.5 μm) to TSP		Ratio of IP (<15 μm) to TSP	
		Left	Right	Left	Right	Left	Right
J21	5	4,511	7,114	0.07	0.03	0.45	0.40
	20	2,658	3,548	0.04	0.05	0.44	0.36
	50	1,076	2,086	0.16	0.04	0.65	0.42

[a] 13.0 μm cut size rather than 15 μm.

[b] 19.0 μm cut size rather than 15 μm.

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The previous discussion was based entirely on data generated by PEDCo. Both PEDCo and MRI operated equipment upwind of the sources. Measurements made by PEDCo and MRI samplers are compared in Table 6-3. The average absolute relative difference in upwind TSP concentrations was 19.9 percent, while the average absolute relative difference in measured TSP concentrations at 5 m downwind was 57.9 percent. These differences appeared to be primarily random, in that some were positive and others were negative and their signed averages were only 2.5 and 17.6 percent, respectively. The additional difference above 25.3 percent at 5 m downwind was attributed to such factors as different flow rates, nonuniform source strength, and slightly offset sampling times.

The measured IP concentrations at 5 m downwind had a 48.4 percent average absolute relative difference, also much higher than the simultaneous PEDCo IP samples, and the concentrations measured by the two groups had a systematic bias. PEDCo's values were consistently higher than MRI's. Both sets of units were calibrated and audited for flow rates, so the difference was suspected to be in the sample handling procedures, which were previously noted to be a major problem. Also, different sampling media were used during the comparability study--PEDCo used mesh-backed Teflon filters and MRI used ringed filters.

The precision of the basic measurement techniques, as evaluated in side-by-side sampling, do not agree with values used in the error analyses cited in Section 3, especially at the 5 m sampling distance. The precision of the hi-vol appears to be ±25 percent or more at 5 m from the source, improving to about ±15 percent at greater distances from the source. The precision of the dichotomous sampler for measuring the IP fraction appears to average ±25 percent or more at all distances. For the error analysis of exposure profiling, this changes the random instrument error from 5 percent to at least 25 percent. For upwind-downwind sampling, the 18.8 percent estimate for hi-vol sampler measurements would still be appropriate if it were applied to samples taken at 20 m or more away from the source.

Comparative Emission Rates

The comparability study was conducted over a 2 week period. The meteorological, source activity, and soil conditions for each test are shown in Table 6-4. This table includes all the variables identified that might influence particulate emission rates.

The most important results of the comparability study, emission rates from simultaneous testing by exposure profiling and the upwind-downwind technique, are presented in Tables 6-5 and 6-6. Table 6-5 shows TSP emission rates and Table 6-6 the inhalable particulate (less than 15 μm) fraction, both in units of lb/VMT.

TABLE 6-3. CONCENTRATIONS MEASURED AT COLLOCATED SAMPLERS

Sampler/ location	Test	Measured concentration, $\mu g/m^3$				Rel diff, %[c]
		PEDCo sampler	Second PEDCo sampler	MRI sampler	Second MRI sampler	
Hi vol						
Upwind	J1	235		254	296	+16
	J2	13999		13803	14163	-0
	J3	8222[a]		3620	10636	-14
	J4	184		226	176	+9
	J5	344		264	124	-56
	J9	285		339	440	+31
	J10	1106		1129	913	-8
	J12	821		1192	1064	+31
	J20	1201		1012	1020	-17
	J21	1060		780	1009	-17
					signed avg	-2.5
					absolute avg	19.9
5 m dwn	J1	3661	4649	-		-
	J2	10635	14407	b		-
	J3	17117[a]	21580	24230		+22
	J4	2457	2719	2194		-16
	J5	3130	5732	1599		-94
	J9	5108	3926	7188		+46
	J10	5668	5009	10057		+62
	J12	2122	2137	819		-89
	J20	3042	4014	4833		+31
	J21	5145	7747	2051		-103
					signed avg	-17.6
					absolute avg	57.9
Dichot, IP						
5 m dwn	J1	1254	1119	1033		-14
	J2	3659	4427	388		-165
	J3	9689	8761	5191		-56
	J4	724	742	529		-32
	J5	1750	2010	1446		-26
	J9	2842	1929	1102		-74
	J10	2748	1771	1825		-21
	J12	801	701	760		+1
	J20	2036	2222	1425		-40
	J21	2653	3764	1828		-55
					signed avg	-48.3
					absolute avg	48.4

a Some loose material in filter folder, concentration may be higher.

b Sampler only ran 12 of 34 min, concentration invalidated.

c See Page 103 for procedure to calculate relative difference.

The data in Tables 6-5 and 6-6 were examined for relationships between sampling methods, sources, and downwind distance. A standard statistical technique was used to determine whether statistically significant. This technique, called Analysis of Variance (ANOVA), was available as a computer program as part of the Statistical Package for the Social Sciences (SPSS). The basis of ANOVA is the decomposition of sums of squares. The total sum of squares in the dependent variable is decomposed into independent components. The program can be used to simultaneously determine the effects of more than one independent variable on the dependent variable. Much has been written about this technique, so further discussion has not been included here. Further information on it can be found in many standard statistical textbooks.

One of the assumptions upon which ANOVA is based is that input data are normally distributed. The TSP and IP emission rates in Tables 6-5 and 6-6 were both found to be skewed, so ANOVA was also run on the data after they were transformed to their natural logarithms. The relationships between emission rates and sampling methods, sources, and downwind distance were the same for the untransformed and transformed data. Therefore, the results with untransformed data are presented herein because they relate directly to the data in Table 6-5 and 6-6.

The outputs from the program are shown Tables 6-7 and 6-8. They consist of the ANOVA results and a multiple classification analysis (MCA). The MCA table can be viewed as a method of displaying the ANOVA results.

The data in Table 6-7 show that sampling method and downwind distance are significant variables for both TSP and IP (A = 0.20). Source was not a significant variable and one of the interrelationships were significant.

Table 6-8 shows the deviation from the total sample mean for the three variables. Also shown are deviations after the effects of the other independent variables are accounted for. The minor changes in these deviations indicate that there are no significant relationships between variables.

The average percent difference between sampling methods (profiling versus upwind-downwind) was calculated from the data in Table 6-8 for both TSP and IP. The resulting differences were 24 and 52 percent, respectively, with profiling producing the higher values in both cases.

Both methods of sampling showed large overall reductions in TSP emission rates with distance. However, the profiling samples at 5 m did not fit the pattern of fairly regular reductions displayed at the other distances and with the upwind-downwind data. In six of ten tests, emission rates by profiling at 5 m were much lower than the corresponding rates at 20 m. These six pairs of inverted values were attributed to the systematic bias documented earlier in this section between PEDCo and MRI inhalable particulate concentrations, in which PEDCo's values were consistently

TABLE 6-4. TEST CONDITIONS FOR COMPARABILITY STUDIES

Test	Date	Start time	Sampling duration, minutes	Source characteristics			Soil properties		Meteorological conditions		
				Passes	Mean speed, mph	Mean weight, ton	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
J1	7/26/79	16:49/16:45[a]	87/84[a]	63/63[a]	19	55	8.9	5.7	74/75[a]	2.8/3.7[a]	C
J2	7/27/79	13:45/13:40	34/38	18/18	19	58	23.4	2.3	77/79	1.4/3.7	A
J3	7/27/79	16:38/16:33	51/54	35/35	24	59	15.8	4.1	85/89	1.3/2.2	B
J4	7/28/79	11:22/11:06	52/63	25/25	20	40	14.6	1.5	68/83	1.1/1.3	A
J5	7/28/79	14:29/14:20	60/62	12/12	18	77	10.6	0.9	85/90	1.4/1.5	A
J9	8/01/79	10:21/10:21	51/59	41/44	19	72	9.4	3.4	83/83	4.8/3.8	B
J10	8/01/79	14:08/14:02	52/47	43/43	19	66	9.4	2.2	88/89	4.4/4.8	C
J12	8/02/79	10:50/10:49	49/49	18/20	15	109	14.2	6.8	80/81	0.8/1.1	A
J20	8/09/79	14:10/14:10	49/46	23/23	17	138	11.6	8.5	73/73	2.5/2.1	B
J21	8/09/79	16:51/16:52	26/21	13/13	15	121	11.6	8.5	79/79	1.6/2.2	B

[a] MRI value/PEDCo value.

TABLE 6-5. CALCULATED SUSPENDED PARTICULATE EMISSION RATES FOR COMPARABILITY TESTS

Test	Downwind distance, m	Emission rate, lb/VMT			Relative difference, %^{a}
		By profiler		By uw-dw TSP	
		Total particulate	<30 µm fraction		
Scrapers					
J1	5	41.4	8.6	10.6	+21
	20	29.1	15.4	11.4	-30
	50			7.8	
	100			2.4	
J2	5	66.5	9.4	18.6	+66
	20	59.9	15.9	16.8	+6
	50	40.0	8.3	7.2	-14
	100			5.3	
J3	5	125.0	50.2	35.6	-34
	20	52.6	24.5	17.8	-32
	50	23.5	8.2	9.8	+18
	100			2.2	
J4	5	27.5	3.9	5.7	+38
	20	22.4	4.8	5.2	+8
	50	15.6	4.0	4.0	0
	100			2.4	
J5	5	96.7	17.7	20.0	+12
	20	46.6	11.5	15.6	+30
	50	15.2	4.5	5.7	+24
	100			1.2	
Haul roads					
J9	5	51.4	15.2	14.1	-8
	20	35.7	22.5	13.6	-49
	50	17.8	8.3	11.1	+29
	100			5.1	
J10	5	54.1	33.0	12.0	-93
	20	20.3	18.5	8.8	-71
	50	7.1	3.4	3.2	-6
	100			neg	
J12	5	16.5	12.9	3.5	-115
	20	5.5	1.9	4.4	+79
	50	2.0	0.3	2.9	+162
	100			0.5	

(continued)

TABLE 6-5 (continued).

Test	Downwind distance, m	Emission rate, lb/VMT			Relative difference, %[a]
		By profiler		By uw-dw TSP	
		Total particulate	<30 μm fraction		
J20	5	36.6	12.3	6.4	-63
	20	31.3	17.7	4.3	-122
	50	20.6	10.7	2.8	-117
	100			neg	
J21	5	76.4	14.2	15.0	+5
	20	40.9	19.2	13.8	-33
	50	25.0	15.2	12.8	-17
	100			8.5	
Mean	5	59.2	17.7	14.2	-22
	20	34.4	15.2	11.2	-30
	50	18.5	7.0	6.8	-3
Std dev	5	33.0	13.8	9.3	(difference signed)
	20	16.3	7.2	5.2	
	50	10.9	4.5	3.6	

[a] See Page 103 for procedure to calculate relative difference.

TABLE 6-6. CALCULATED INHALABLE PARTICULATE (<15 μm) EMISSION RATES FOR COMPARABILITY TESTS

Test	Downwind distance, m	IP emission rate, lb/VMT		Relative difference, %[c]
		By profiler	By uw-dw	
Scrapers				
J1	5	4.2	3.1	-30
	20	7.2	3.5	-69
	50		3.2	
J2	5	4.0	2.5	-46
	20	6.8	2.4	-96
	50	5.2	2.0	-89
J3	5	26.1	14.0	-60
	20	11.0	4.2	-89
	50	4.1	3.6	-13
J4	5	1.7	1.0	-52
	20	2.4	0.9	-91
	50	2.2	1.3	-51
J5	5	10.0	5.8	-53
	20	5.4	1.1	-132
	50	2.5	1.4	-56
Haul roads				
J9	5	7.4	7.2	-3
	20	11.8	8.9	-28
	50	3.7	4.4	+17
J10	5	17.7	6.0	-99
	20	12.4	7.6	-49
	50	1.8	4.9[a]	+93
J12	5	7.9	0.6	-172
	20	1.1	1.2	+9
	50	0.2	0.5	+86
J20	5	5.4	3.8	-35
	20	12.0	5.7[b]	-71
	50	5.8	7.1[b]	+20
J21	5	6.0	6.3	+5
	20	11.4	5.5	-70
	50	10.3	6.3	-48
Mean	5	9.0	5.0	-57
	20	8.1	4.1	-66
	50	4.0	3.5	-13
Std dev	5	7.4	3.9	(signed difference)
	20	4.2	2.8	
	50	2.9	2.2	

[a] This dichotomous sampler value could not be corrected to a 15 um cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 13.6 um.

[b] These dichotomous sampler values could not be corrected to a 15 um cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 19.0 um

[c] See Page 103 for procedure to calculate relative difference.

TABLE 6-7. ANALYSIS OF VARIANCE RESULTS

TSP BY METHOD SOURCE DIST.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	994.413	4	248.603	3.588	.012
METHOD	119.001	1	119.001	1.717	.196
SOURCE	57.492	1	57.492	.830	.367
DIST	817.920	2	408.960	5.902	.005
2-WAY INTERACTIONS	186.270	5	37.254	.538	.747
METHOD SOURCE	95.011	1	95.011	1.371	.248
METHOD DIST	44.826	2	22.413	.323	.725
SOURCE DIST	55.749	2	27.874	.402	.671
3-WAY INTERACTIONS	21.643	2	10.821	.156	.856
METHOD SOURCE DIST	21.643	2	10.821	.156	.856
EXPLAINED	1202.326	11	109.302	1.577	.137
RESIDUAL	3256.810	47	69.294		
TOTAL	4459.136	58	76.882		

IP BY METHOD SOURCE DIST.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	269.278	4	67.319	3.499	.014
METHOD	129.377	1	129.377	6.724	.013
SOURCE	28.422	1	28.422	1.477	.230
DIST	111.478	2	55.739	2.897	.065
2-WAY INTERACTIONS	76.587	5	15.317	.796	.558
METHOD SOURCE	.825	1	.825	.043	.837
METHOD DIST	41.533	2	20.767	1.079	.348
SOURCE DIST	33.984	2	16.992	.883	.420
3-WAY INTERACTIONS	1.833	2	.917	.048	.954
METHOD SOURCE DIST	1.833	2	.917	.048	.954
EXPLAINED	347.697	11	31.609	1.643	.118
RESIDUAL	904.308	47	19.241		
TOTAL	1252.005	58	21.586		

TABLE 6-8. MULTIPLE CLASSIFICATION ANALYSIS (ANOVA)

TSP BY METHOD SOURCE DIST. GRAND MEAN = 12.08

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
METHOD							
Profiler 1	29	1.44		1.37			
Uw-dw 2	30	-1.40		-1.33			
			.16		.16		
SOURCE							
Scrapers 1	29	.98		.91			
Haul trucks 2	30	-.95		-.88			
			.11		.10		
DIST							
5 m 1	20	3.87		3.83			
20 m 2	20	1.10		1.06			
50 m 3	19	-5.23		-5.15			
			.43		.43		
MULTIPLE R SQUARED					.223		
MULTIPLE R					.472		

IP BY METHOD SOURCE DIST. GRAND MEAN = 5.66

VARIABLE + CATEGORY	N	UNADJUSTED DEV'N	UNADJUSTED ETA	ADJUSTED FOR INDEPENDENTS DEV'N	ADJUSTED FOR INDEPENDENTS BETA	ADJUSTED FOR INDEPENDENTS + COVARIATES DEV'N	ADJUSTED FOR INDEPENDENTS + COVARIATES BETA
METHOD							
Profiler 1	29	1.51		1.46			
Uw-dw 2	30	-1.46		-1.41			
			.32		.31		
SOURCE							
Scrapers 1	29	-.73		-.74			
Haul trucks 2	30	.71		.72			
			.16		.16		
DIST							
5 m 1	20	1.38		1.37			
20 m 2	20	.47		.46			
50 m 3	19	-1.95		-1.92			
			.30		.30		
MULTIPLE R SQUARED					.215		
MULTIPLE R					.464		

higher and the average difference was 48.4 percent. MRI generated the the 5 m profiling data; PEDCo generated the 20 and 50 m data. This difference was important because the IP and FP concentration data are used to extrapolate the less than 30 μm fraction in profiling calculations.

The IP emission data by both sampling methods displayed almost as much reduction with distance as the TSP data. This is a surprising finding, in that very little deposition of sub-15 μm particles would be expected over a 50 m interval.

The reason for the relatively ppr comparisons between emission rates obtained by the two sampling/calculation methods can be traced primarily to the precision of the sampling methods. MRI and PEDCo samplers located at the same distances from the source and operated simultaneously produced TSP concentrations that differed by an average of 58 percent, greater than the average difference of 24 percent in the resulting TPS emission rates. Similarly, a 48 percent average difference in IP concentrations explains much of the 52 percent difference in IP emission rates.

Both methods are entirely dependent on the measured IP and or/TSP values for calculating emission rates. The accuracy of the methods can improve on the precision of individual measurements to the extent that multiple measurements are used in the calculation of a single emission rate. Both profiling and upwind-downwind techniques as employed in the comparability study utilized two IP measurements, and upwind-downwind used two TSP measurement to obtain final emission rates at each distance.

Results from the two sampling methods were compared with each other rather than a known standard, so it is impossible to establish from the data which is more accurate. If the error analyses described in Section 3 were revised to reflect the sampling precisions reported above, exposure profiling would show lower total error levels than upwind-downwind sampling at the same distance from the source. For the distances routinely used for the respective methods in the reminder of the field work, upwind-downwind sampling would have lower indicated total error. Whichever sampling method is used, it appears from the modified error analyses that the current state-of-the-art in fugitive dust emission testing is ±25 to 50 percent accuracy.

DEPOSITION RATES BY ALTERNATIVE MEASUREMENT METHODS

Analytical Approaches

Four different approaches for describing the deposition rate for each test were considered:

1. Reduction in apparent emission rate per unit distance form the source (deposition = dg/dx)

2. Reduction in apparent emission rate per unit time (deposition = -dg/dt); also, this deposition rate plotted as a function of total travel time away from source

3. Dustfall measurements at successive distances expressed as percentages of the calculated total particulate emission rate

4. Total percent reduction in apparent emission rate over 50 or 100 m compared with percent of emissions greater than 15 µm diameter (under the assumption that most large particles settle out and few small ones do)

In the first approach above, deposition rate is the slope of a curve of TSP or IP emission rate versus distance, applied to either profiling or upwind-downwind data. Deviations from a smooth, idealized deposition curve were magnified by this method of determining the slope of a curve at different points. With the scatter in the emission data of Tables 6-5 and 6-6, calculated deposition rates varied tremendously, including many negative values.

Converting the deposition data to a time rather than distance basis in the second approach was an attempt to remove the effect of wind speed variation on deposition rates. The table of time deposition rates and plot of deposition rate versus total travel time had almost as much scatter as the data from the first approach. When the deposition rates were normalized to percents of the initial emission rate for that test, the data showed a perceptible relationship, as presented in Figure 6-4.

Dustfall, a direct measurment of particle deposition, could not be equated with the calculated TSP or IP values described above because dustfall contains deposition of all particle sizes, not just that in the TSP or IP size range. Net dustfall rates were compared with reductions in total particulate (TP) emission rates from the 5 m profiler to the 50 m profiler. However, the same scatter noted above in the profiling data combined with similar scatter in the dustfall data obscured any pattern in deposition rates.

All dustfall measurements were taken by collocated duplicate readings. The average difference for downwind duplicate measurements in the 10 tests was 40.5 percent, even greater than differences in concurrent TSP and IP measurements. In addition, several (13 out of 57) of the net dustfall readings were negative because the upwind value was higher than the downwind one. Allowing for the scatter in the data, dustfall rates appeared to agree better in magnitude with the TSP deposition rates calculated by the first approach than with TP desposition rates.

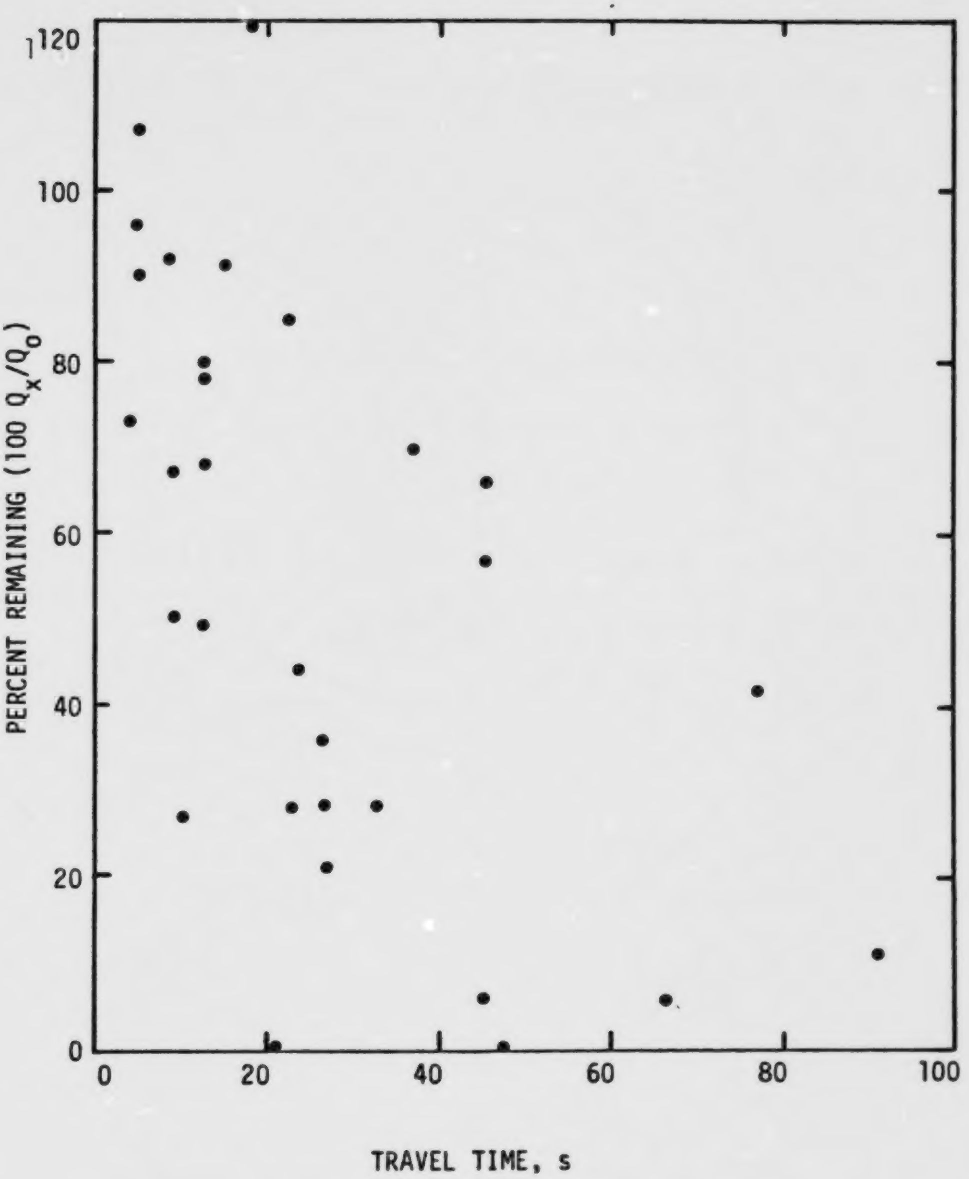

Figure 6-4. Deposition rates as a function of time.

The fourth approach evalutated for describing deposition in the comparability tests was to relate the measured deposition to the percent of particles in the plume susceptible to deposition. Particles greater than 15 μm were assumed to be highly susceptible to deposition, partially because this fractional value was readily available from the test data. However, none of the correlations between deposition rates and particles greater than 15 μm in the plume were found to be significant (at the 0.05 to 0.20 level):

Distance	Size meas. method	No. tests	r
5 m	Impactor	10	0.17
20 m	Impactor	10	0.29
20 m	Dichot	10	-0.36

No reason was identified for these low correlations.

Average Deposition

Although the approaches evaluated above did not provide a usable relationship for estimating the rate of deposition of particulate from the dust plumes, deposition was definitely occurring in the comparability tests. This was readily apparent from examination of the average emission rates at successive distances from the source, as shown at the bottom of Tables 6-5 and 6-6.

These reductions in average emission rate with distance are shown in Figure 6-5 in terms of depletion factors, the ratios between the depleted emission rate measured at distance x and the initial emisison rate (Q_x/Q_0). Q_0 was the emission rate determined by either profiling of upwind-downwind sampling at 5 m, which was assumed to be the edge of the mixing cell and distance at which deposition actually began.

This depletion factor approach was applied to the individual test data to determine whether variables such as stability class, wind speed, or initial particle size distribution affected the deposition rate discernibly. The resulting data are presented in Table 6-9. Deposition rates did not appear to be closely related to any of the above three variables in the 10 comparability tests.

Theoretical Deposition Functions

Three different theoretical deposition functions have been widely used in atmospheric dispersion modeling to simulate dry particle deposition: source depletion, surface depletion, and tilted plume functions. The depletion factors for these three alternative functions for the first 200 m (200 m is greater than the sampling distances) are shown in Figure 6-6.

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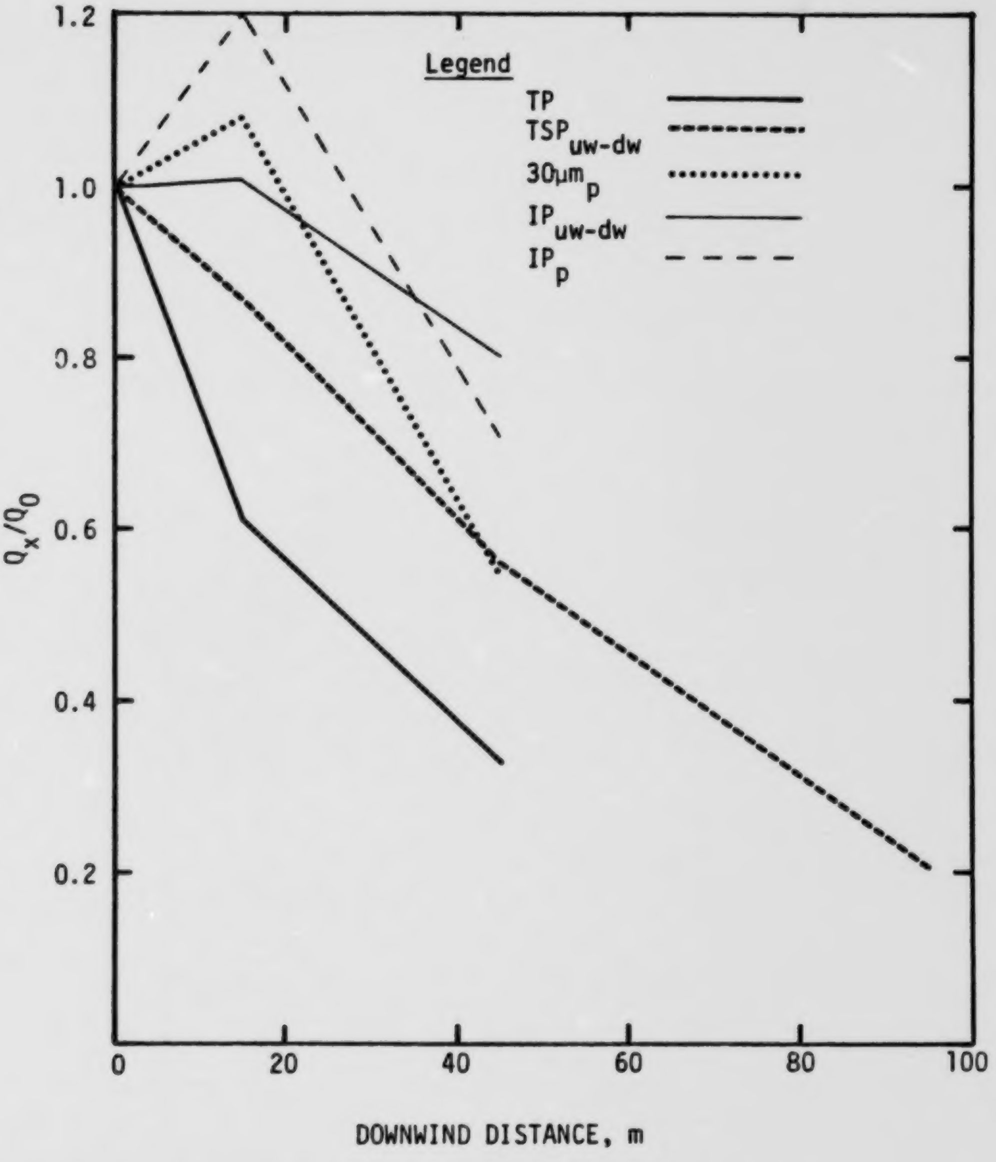

Figure 6-5. Average measured depletion rates.

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The input conditions for all three functions were: wind speed = 1.0 m/s, gravitational settling velocity of monodisperse particles = 0.1 m/s, emission height = 2.0 m, and stability class as indicated on the figure.

One observation that can be made from the curves, and that would be more obvious if the curves were extended beyond 200 m, is that much of the total deposition occurs within this first 200 m. However, these are theoretical curves and it should not be implied that the field study measurements at 100 m account for the bulk of deposition or provide a rough estimate of fully depleted emission rates. This could only be determined with actual measurements of deposition at distances of 1 km and beyond.

The tilted plume curve was closest of the three theoretical functions to the average deposition rates from the comparability study (plotted in Figure 6-5). There is no assurance that this function continues to provide the best fit at distances in the range of 1 to 20 km that are of greatest concern in dispersion modeling. Not that the tilted plume depletion is not very dependent on stability class; the test data did not appear to be closely realted to stability class either.

The depletion factor in the tilted plume function is given in the following equation:

$$Q_x Q_o = 1 - \frac{1}{(1-n/2)(h\ u/xv_d-1) + 2} \qquad \text{(Eq. 27)}$$

where n = Sutton's diffusion parameter, which varies by stability class:

	n
A	0.15
B	0.26
C-D	0.48
E-F	0.57

h = emission height, m

u = wind speed, m/s

x = downwind distance, m

v_d = deposition velocity, 10^{-2} m/s

The average deposition rates from Figure 6-5 are plotted together with tilted plume curves representing average test conditions (B stability, u = 2.6 m/s, and h_o = 2.0 m) for four different v_d values in Figure 6-7. It was assumed that v_d and v_g (gravitational settling velocity); Stokes law $v_g = 0.00301 pD^2$) was used to calculate corresponding particle sizes for the three theoretical deposition curves:

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TABLE 6-9. DEPLETION FACTORS FOR COMPARABILITY TESTS

Test	TSP depletion factor			IP depletion		Stability class	Wind speed, m/s	Init. partic. size	
	20 m	50 m	100 m	20 m	50 m			% >15 μm	% >30 μm
J1	1.08	0.74	0.23	1.13	1.03	C	3.7	89	78
J2	0.90	0.39	0.28	0.96	0.80	A	3.7	92	86
J3	0.50	0.28	0.06	0.30	0.25	B	2.2	81	69
J4	0.91	0.70	0.42	0.90	1.30	A	1.3	93	86
J5	0.78	0.28	0.06	0.19	0.24	A	1.5	88	80
J9	0.96	0.79	0.36	1.24	0.61	B	3.8	82	67
J10	0.73	0.27	0	1.27	0.82	C	4.8	71	51
J12	1.26	0.83	0.14	2.00	0.83	A	1.1	75	59
J20	0.67	0.44	0	1.25	1.11	B	2.1	82	60
J21	0.92	0.85	0.57	0.87	1.00	B	2.2	90	78

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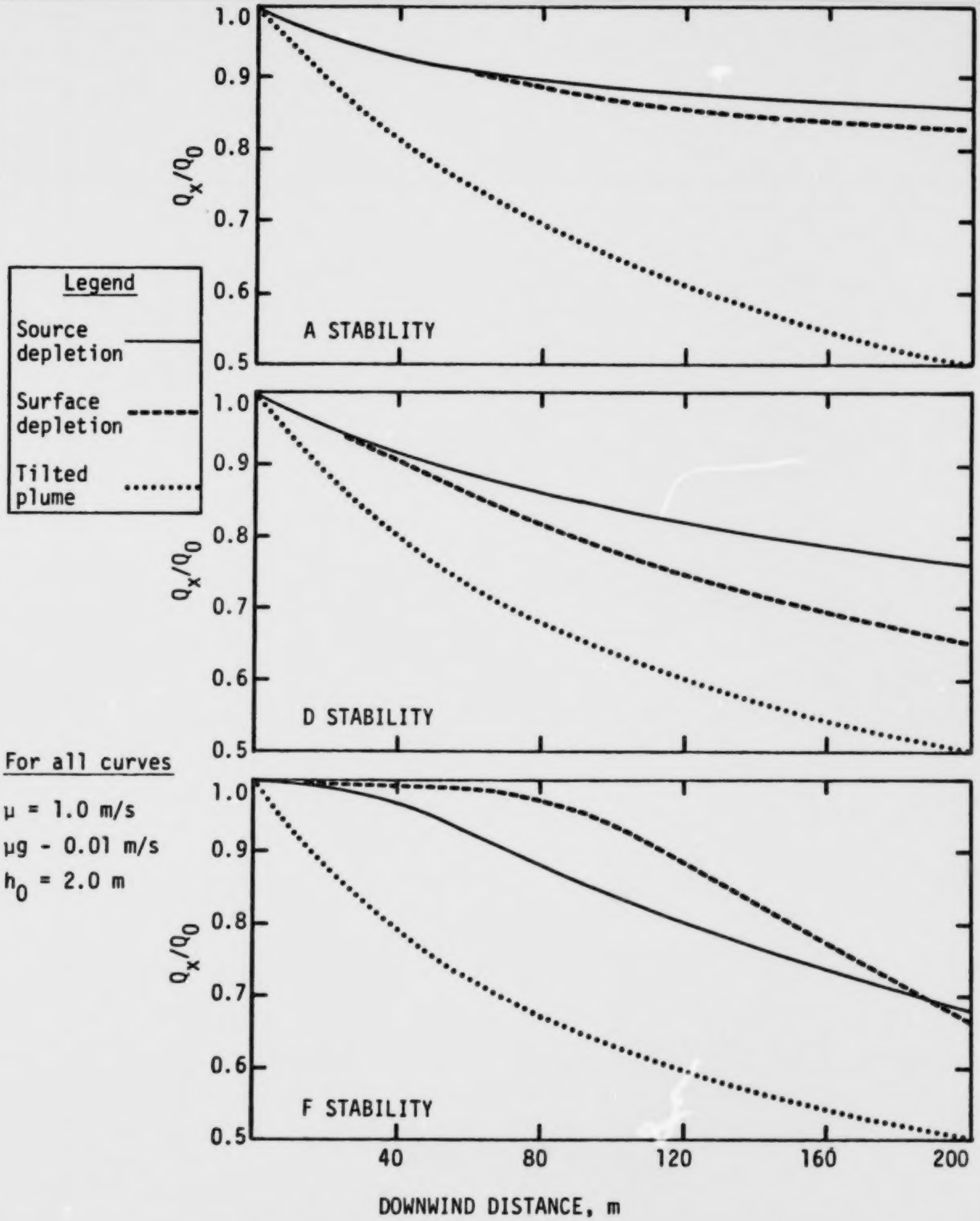

Figure 6-6. Depletion rates by theoretical deposition functions.

v_g, cm/s	D, um	Test curve best matched
2	16	IP_{uw-dw}, IP_p
5	26	30 μm_p
15	45	TSP_{up-dw}
30	63	TP

Actually, deposition rates for small particles onto the ground have been observed to be greater than can be explained by gravitational settling velocity, and the concept of a deposition velocity v_d greater than v_g has been developed to account for this faster deposition. Since v_g is less than or equal to v_dd, the equivalent particle sizes tabulated above would also be smaller than shown. If the data from the comparability tests had been demonstrated to be more accurate than they were, the matching of theoretical and test data in Figure 6-7 could have been used to estimate a v_g/v_d relationship for calibrating a mining fugitive dust deposition function. The available data indicate a v_g/v_d ratio of about 0.8.

Summary of Deposition Results

Deposition was definitely occurrring in the 10 comparability tests, with an average of 63 percent reduction in profiler 30 μm emission rates in 50 m and 79 percent reduction in upwind-downwind TSP emission rates in 100 m. Deposition rates in individual tests were obscured by data scatter, so an empirical function could not be developed. However, the average deposition rates expressed as depletion factors (Q_x/Q_o) agreed reasonably well with theoretical deposition functions. Of the three theoretical functions examined, the test data appeared to agree best with the tilted plume model (subjective evaluation).

Dustfall data had less precision than the ambient measurements on which the emission rate depletion factors were based. Subsequently evaluation of dustfall data from tests other than the

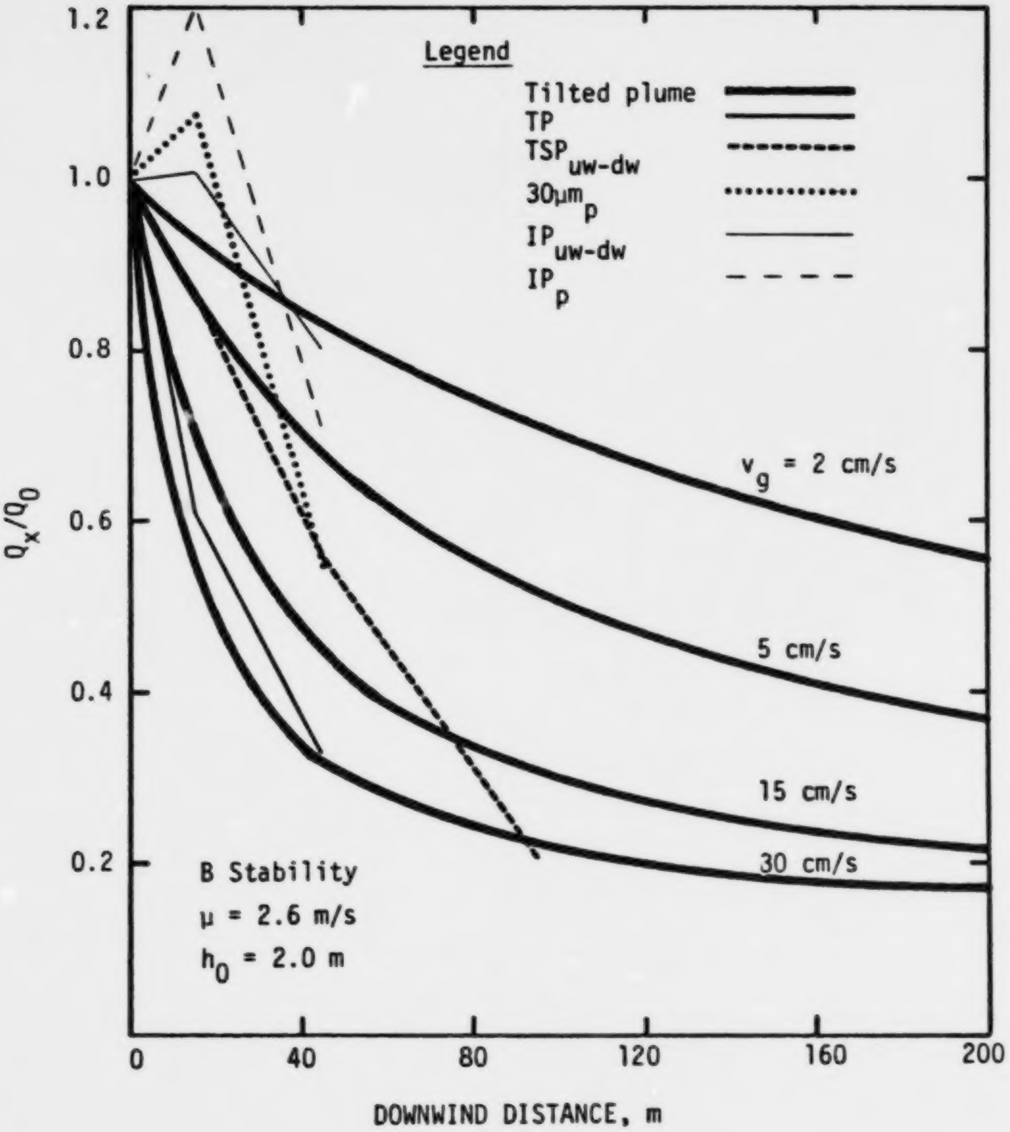

Figure 6-7. Average measured depletion rates compared to predicted tilted plume depletion.

comparability tests showed that this method is reproducible as long as there are not wind direction reversals during the sampling period. A full discussion of dustfall measurement as a method for quantifying deposition rates is presented in Section 12. A summary discussion of deposition is included in Section 14.

SECTION 7

RESULTS FOR SOURCES TESTED BY EXPOSURE PROFILING

SUMMARY OF TESTS PERFORMED

As previously discussed, exposure profiling was used to test particualte emissions from haul trucks, light-duty and medium duty vehicles, scrapers (travel mode) and graders. These sources were tested at three mines during the period July 1979 through August 1980.

A total of 63 successful exposure profiling tests were conducted at the three mines/four visits. They were distributed by source and by mine as follows:

Source	Controlled/ uncontrolled	Number of tests Mine 1	Mine 2	Mine 1W	Mine 3
Haul trucks	U	6	6	3	4
	C	0	4	0	5
Light- and med.- duty vehicles	U	3	4	0	3
	C	2	0	0	0
Scrapers	U	5	6	2	2
Graders	U	0	5	0	2

Light and variable wind conditions were encountered at Mine 1 during the test period July-August 1979, with winds occasionally reversing and traffic-generated emissions impacting on the upwind sampling station. These events were termed "bad passes."

Table 7-1 lists the site conditions for the exposure profiling tests of dust emissions generated by haul trucks. The comparability tests are indicated by an asterisk after the run number. In addition to the testing of uncontrolled sources, watering of haul roads was tested as a control measure.

Table 7-2 gives the road and traffic characteristics for the exposure profiling tests of haul trucks. This source category exhibited a wide range of road and traffic characteristics, indicating a good

TABLE 7-1. EXPOSURE PROFILING SITE CONDITIONS - HAUL TRUCKS

Mine/Site[a]	Profiler						Meteorology	
	Run[b]	Date	Start time	Sampling duration (min)	Vehicle passes		Temp. (°C)	Wind speed[c] (m/s)
					Good	Bad		
Mine 1/Site 2	J-6	7/30/79	16:06	67	2	37	24.5	0.9
	J-9*	8/01/79	10:21	51	41	0	28.3	4.8
	J-10*	8/01/79	14:08	52	43	2	31.0	4.4
	J-11[d]	8/01/79	17:39	48	40	0	30.5	4.2
	J-12*	8/02/79	10:50	49	18	1	26.7	0.8
	J-20*	8/09/79	14:10	49	23	0	23.0	2.5
	J-21*	8/09/79	16:51	26	13	1	25.0	1.6
Mine 2/Site 1	K-1	10/11/79	10:21	86	65	0	14.6	6.2
Mine 2/Site 3 (Watered)	K-6	10/15/79	11:03	177	84	0	17.8	3.4
Mine 2/Site 3	K-7	10/15/79	14:50	53	57	0	23.5	2.6
Mine 2/Site 3 (Watered)	K-8	10/16/79	11:02	105	43	0	10.3	5.7
Mine 2/Site 3	K-9	10/16/79	13:18	89	63	0	12.0	5.0
	K-10	10/17/79	10:37	65	40	0	10.6	5.0
	K-11	10/17/79	12:05	64	50	0	12.5	5.2
	K-12	10/17/79	13:38	58	43	0	15.5	5.4
Mine 2/Site 3 (Watered)	K-13	10/23/79	10:47	73	78	0	4.0	3.7
Mine 1/Site 5	L-1	12/07/79	14:04	92	57	0	0.7	1.9

(continued)

TABLE 7-1 (continued)

Mine/Site[a]	Profiler						Meteorology	
	Run[b]	Date	Start time	Sampling duration (min)	Vehicle passes		Temp. (°C)	Wind speed[c] (m/s)
					Good	Bad		
Mine 1/Site 6	L-2	12/08/79	13:12	4[e]	23[f]	0	12.2	6.9
	L-3	12/08/79	13:45	48	26	0	13.2	6.5
	L-4	12/08/79	15:04	47	32	0	13.6	6.1
Mine 3/Site 1	P-1	7/25/80	16:28	57	15	0	35	3.8
Mine 3/Site 2	P-2	7/26/80	10:25	95	10	2	27	1.8
	P-3	7/27/80	9:10	89	18	0	27	3.8
Mine 3/Site 2 (Watered)	P-4	7/28/80	8:41	135	48	0	27	3.7
Mine 3/Site 2	P-5	7/29/80	7:32	108	38	0	32	2.8
Mine 3/Site 2 (Watered)	P-6	7/30/80	7:12	112	48	0	29	2.2
	P-7	7/31/80	7:27	95	35	0	29	2.5
	P-8	7/31/80	9:22	103	49	0	29	3.0
	P-9	8/01/80	7:51	142	48	0	27	3.7

[a] Mine 1/Site 2 - Mine B tipple road (haul road to crusher)
Mine 2/Site 1 - 250m west of haul truck unloading station.
Mine 2/Site 3 - 1 mile west of haul truck unloading station.
Mine 1/Site 5 - About 100m east of haul road sites for summer testing.
Mine 1/Site 6 - About 250m northeast of haul road sites for summer testing.
Mine 2/Site 1 - Near Ramp 5 east of lake.
Mine 2/Site 2 - Between Ramps 2 and 3.

[b] Asterisk indicates comparability test.

[c] Value at 3m above the ground, interpolated from 1.5 and 4.5m warm wire anemometer data using a logarithmic profile.

[d] MRI comparative equipment run; PEDCO did not test.

[e] Represents total time that the profiler ran properly; there was a prior period for which isokinetic flows could not be obtained.

[f] Represents the total number of passes during the attempted run (while the equipment, other than the profiler, was operating).

TABLE 7-2. ROAD AND TRAFFIC CHARACTERISTICS - HAUL TRUCKS

Run	Road surface properties			Vehicle mix	Mean vehicle speed (km/h)	Mean vehicle weight (tons)	Mean No. of vehicle wheels
	Loading (g/m^2)	Silt (%)	Moist. (%)				
J-6		7.9[a]	5.4[a]	———	-	-	-
J-9*	40	9.4	3.4	About 2/3 haul trucks; rest light duty trucks	31	65	8.0
J-10*	130	9.4	2.2	About 2/3 haul trucks; rest light duty trucks	31	60	7.7
J-11	82	8.2	4.2	Mostly unloaded haul trucks	32	60	9.9
J-12*	235	14.2	6.8	Mostly haul trucks	24	99	9.5
J-20*	330	11.6	8.5	Mostly loaded haul trucks	27	125	10.0
J-21*	330	b	b	Mostly haul trucks	24	110	9.3
K-1	780	7.7	2.2	Combination of heavy and light duty trucks	53	63	6.1
K-6	354	2.2	7.9	Combination haul trucks and light duty trucks	56	89	7.4
K-7	361	2.8	0.9	Mostly light duty trucks	55	24	4.9
K-8	329	3.1	1.7	Combination haul trucks and light duty trucks	58	65	6.3
K-9	470	4.7	1.5	Combination haul trucks and light duty trucks	47	74	6.7
K-10	290	7.7	2.0	Combination haul trucks and light duty trucks	58	69	6.6
K-11	290	8.9	2.0	Combination haul trucks and light duty trucks	48	73	6.5
K-12	290	11.8	2.3	Combination haul trucks and light duty trucks	58	95	7.3

(continued)

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TABLE 7-2 (continued)

Run	Road surface properties			Vehicle mix	Mean vehicle speed (km/h)	Mean vehicle weight (tons)	Mean No. of vehicle wheels
	Loading (g/m^2)	Silt (%)	Moist. (%)				
K-13	67	1.8	2.7	Combination haul trucks and light duty trucks	51	64	6.6
K-26	67	b	b	Combination haul trucks and light duty trucks	51	84	6.8
L-1	450	13.0	7.7	Mostly haul trucks	42	95	8.8
L-2	104	b	b	Mostly haul trucks	39	96	9.8
L-3	550	13.8	4.9	Mostly haul trucks	32	107	9.3
L-4	1410	18.0	5.1	Mostly haul trucks	32	86	8.3
P-1	489	4.7	0.4	Mostly haul trucks	43	79	8.5
P-2	489	4.7	0.4	About 1/2 haul trucks; rest light/medium vehicles	42	42	7,2
P-3	580	4.1	0.3	Haul trucks	50	94	9.7
P-4	200	2.0	0.3	About 1/2 haul trucks; rest light/medium vehicles	51	55	7.6
P-5	131	3.1	c	About 1/2 haul trucks; rest light/medium vehicles	50	47	7.1
P-6	489	2.8	2.9	Mostly light/medium vehicles	51	25	5.6
P-7	458	2.4	1.5	About 1/2 haul trucks; rest light/medium vehicles	50	61	7.6
P-8	680	7.7	15.3	About 1/2 haul trucks; rest light/medium vehicles	47	47	7.5
P-9	438	1.6	20.1	About 1/2 haul trucks; rest light/medium vehicles	50	58	8.7

[a] Average of more than one sample.
[b] No sample taken.
[c] Moisture below detectable limits.
*Comparability test

potential for identifying and quantifying correction parameters. Most tests involved a blend of vehicle types dominated by haul trucks. Silt and moisture values were determined by laboratory analysis of road surface aggregate samples obtained from the test roads. Mean vehicle speeds and weights are arithmetic averages for the mixes of vehicles which passed over the test roads during exposure profiling.

Table 7-3 lists the site conditions for the exposure profiling tests of dust emissions generated by light- and medium-duty vehicles. In addition to the testing of uncontrolled roads, the application of calcium chloride to an access road was tested as a control measure.

Table 7-4 gives the road and traffic conditions for the exposure profiling tests of light- and medium-duty vehicles. Small variations in mean vehicle weight and mean number of vehicle wheels were observed for this source category. No access roads were available at Mine 2, so light-duty vehicles were tested at a haul road site.

Table 7-5 lists the site conditions for the exposure profiling tests of dust emissions generated by scrapers (travel mode). Table 7-6 gives the road and traffic conditions for the exposure profiling tests of scrapers. All scrapers tested were four-wheeled vehicles, which excluded this parameter from consideration as a correction factor.

Table 7-7 lists the site conditions for the exposure profiling tests of dust emissions generated by graders. Table 7-8 gives the road and traffic conditions for the exposure profiling tests of graders. All graders tested were six-wheeled vehicles and weighed 14 tons. Therefore, mean vehicle weight and mean number of vehicle wheels were excluded from consideration as correction factors.

RESULTS

The measured emission rates are shown in Tables 7-9 through 7-12 for haul trucks, light- and medium-duty vehicles, scrapers, and graders, respectively. In each case, emission rates are given for TP, SP, IP, and FP.

For certain runs, emission rates could not be calculated. For haul truck L-2, the profiler samples did not maintain a consistent flow rate. Haul truck run J-6 was not analyzed because of the predominance of bad passes. the emissions from run J-7, the access road treated with calcium chloride, were to low to be measured. Scraper run P-15 produced only a TP emission factor; questionable results from a single dichotomous sampler prevented calculation of reliable emission rates for SP, IP, and FP.

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TABLE 7-3. EXPOSURE PROFILING SITE CONDITIONS - LIGHT AND MEDIUM DUTY VEHICLES

Mine/Site[a]	Profiler						Meteorology	
	Run	Date	Start time	Sampling duration (min)	Vehicle passes		Temp. (°C)	Wind speed[b] (m/s)
					Good	Bad		
Mine 1/Site 3 ($CaCl_2$ treated)	J-7	7/31/79	14:09	59	87	17	28.3	1.1
	J-8	7/31/79	15:47	68	95	65	30.0	1.6
Mine 1/Site 4	J-13	8/08/79	11:29	26	59	0	25.5	2.9
	J-18	8/08/79	13:43	21	34	0	26.5	3.7
	J-19	8/08/79	14:53	31	70	0	26.8	3.6
Mine 2/Site 2	K-2	10/13/79	12:23	55	150	0	8.3	5.5
	K-3	10/13/79	15:21	58	150	0	12.1	4.8
	K-4	10/14/79	11:45	67	150	0	16.2	3.1
	K-5	10/14/79	13:19	68	150	0	20.4	4.3
Mine 3/Site 3	P-10	8/02/80		Aborted test				
	P-11	8/04/80	13:07	73	100	0	35	5.8
	P-12	8/04/80	15:33	60	125	0	35	5.2
	P-13	8/04/80	17:14	55	100	0	29	4.2

[a] Mine 1/Site 3 - Mine access road treated with calcium chloride.
Mine 1/Site 4 - County access road.
Mine 2/Site 2 - 50 m west of haul truck unloading station.
Mine 3/Site 3 - Near Ramp 14 north of pit.

[b] Value at 3 m above the ground, interpolated from 1.5 and 4.5 m warm wire anemometer data using a logarithmic profile.

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TABLE 7-4. ROAD AND TRAFFIC CHARACTERISTICS - LIGHT AND MEDIUM DUTY VEHICLES

Run	Road surface properties			Vehicle mix	Mean vehicle speed (km/h)	Mean vehicle weight (tons)	Mean No. of vehicle wheels
	Loading (g/m^2)	Silt (%)	Moist. (%)				
J-7	700	3.0	3.6	Mostly light duty vehicles	40	7	4.2
J-8	700	3.0	3.6	Mostly light duty vehicles	40	3	4.0
J-13	138	10.1	1.0	Light duty vehicles	40	2.2	4.0
J-18	540	8.8	1.1	Light duty vehicles	40	2.6	4.0
J-19	540	8.2	0.9	Light duty vehicles	40	2.3	4.1
K-2	120	4.9	1.6	Light duty vehicles	56	2.3	4.0
K-3	120	4.9	1.6	Light duty vehicles	56	2.4	4.0
K-4	909	5.3	1.7	Light duty vehicles	56	2.4	4.0
K-5	909	5.3	1.7	Light duty vehicles	56	2.4	4.0
P-11	108	5.5	0.9	Mostly pickups	68	2	4.0
P-12	108	5.5	0.9	Mostly pickups	69	2	4.0
P-13	108	5.5	0.9	Mostly pickups	69	2	4.0

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TABLE 7-5. EXPOSURE PROFILING SITE CONDITIONS - SCRAPERS

	Profiler						Meteorology	
					Vehicle passes			
Source[a]	Run[b]	Date	Start time	Sampling duration (min)	Good	Bad	Temp. (°C)	Wind speed[c] (m/s)
Mine 1/Site 1	J-1*	7/26/79	16:49	87	63[d]		23.3	2.8
	J-2*	7/27/79	13:45	34	18	15[e]	25.0	1.4
	J-3*	7/27/79	16:38	51	35		29.4	1.3
	J-4*	7/28/79	11:22	52	25	5	20.0	1.1
	J-5*	7/28/79	14:24	60	12	2	29.5	1.4
Mine 2/Site 4	K-15	10/25/79	11:54	13	6	0	5.0	3.9
	K-16	10/26/79	11:07	41	10	0	8.8	2.6
	K-17	10/26/79	15:22	18	31	0	12.0	4.0
	K-18	10/26/79	15:59	37	30	0	13.1	2.6
	K-22	10/29/79	9:08	110	20	0	5.0	3.0
	K-23	10/29/79	13:23	43	20	0	6.1	4.6
Mine 1/Site 7	L-5	12/12/79	10:40	14	20	0	3.5	8.6
	L-6	12/12/79	11:22	22	15	0	4.2	9.4
Mine 3/Site 4	P-14	8/06/80		Aborted test				
	P-15	8/08/80	14:02	43	4	1	32	1.6
	P-18	8/10/80	16:18	33	18	0	27	3.9

[a] Mine 1/Site 1 - Temporary scraper road at reclamation site.
Mine 2/Site 4 - 250 m north of north pit area.
Mine 1/Site 7 - About 1 mile northeast of haul road sites for summer testing.
Mine 3/Site 4 - 100 m south of pit.

[b] Asterisk indicates comparability test.

[c] Value at 3 m above the ground, interpolated from 1.5 and 4.5 m warm wire anemometer data using a logarithmic profile.

[d] Represents total passes; pass quality was not recorded.

[e] Combination of marginal and bad passes.

TABLE 7-6. ROAD AND TRAFFIC CHARACTERISTICS - SCRAPERS

Run[g]	Road surface properties			Vehicle mix	Mean vehicle speed (km/h)	Mean vehicle weight (tons)	Mean No. of vehicle wheels
	Loading (g/m²)	Silt (%)	Moist. (%)				
J-1*	121	8.9[a]	5.7[a]	Mostly scrapers	31	50	4.1
J-2*	313	23.4[a]	2.3[a]	Mostly scrapers	31	53	4.0
J-3*	310	15.8	4.1	Mostly scrapers	39	54	4.1
J-4*	55	14.6[a]	1.5[a]	Unloaded scrapers	32	36	4.0
J-5*	310	10.6[a]	0.9[a]	Loaded scrapers	29	70	4.0
K-15	b	b	b	Mostly unloaded scrapers[c]	45	46	4.0
K-16	384	25.2[d]	6.0	All scrapers	48	64	4.0
K-17	384	25.2[d]	6.0	Mostly scrapers	37	57	4.1
K-18	384	25.2[d]	6.0	All scrapers	40	66	4.0
K-22	301	21.6	5.4	All unloaded scrapers	51	45	4.0
K-23	318	24.6	7.8	All scrapers	45	54	4.0
L-5	238	21.0	e	All scrapers	34	53	4.0
L-6	238	21.0	e	All scrapers	32	50	4.0
P-15	f	7.2	1.0	Mostly scrapers	26	42	4.0
P-18	f	7.2	1.0	Scrapers	16	64	4.0

[a] Average of more than one sample.
[b] No sample taken.
[c] Test stopped prematurely; scraper drivers quit for lunch.
[d] Average silt of Runs K-29 to K-23.
[e] Unrepresentative sample taken after grader pass; sample not analyzed.
[f] Sample not analyzed for loading.
[g] Asterisk indicates comparability test.

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TABLE 7-7. EXPOSURE PROFILING SITE CONDITIONS - GRADERS

	Profiler						Meteorology	
					Vehicle passes			
Mine/Site[a]	Run[b]	Date	Start time	Sampling duration (min)	Good	Bad	Temp. (°C)	Wind speed[b] (m/s)
Mine 2/Site 4	K-19	10/27/79	10:24	57	40	0	10.2	5.2
	K-20	10/27/79	11:46	59	40	0	13.4	4.5
	K-21	10/27/79	13:34	49	40	0	17.4	4.3
Mine 2/Site 5	K-24	10/30/79	10:16	35	30	0	6.5	4.4
	K-25	10/30/79	11:16	39	30	0	7.8	4.6
Mine 3/Site 4		8/10/80	17:45	129	9	0	27	3.5
	P-17	8/10/80	13:28	67	15	0	27	1.9

[a] Mne 2/Site 4 - 250 m north of north pit area.
Mine 2/Site 5 - 250 m northwest of haul truck unloading station.
Mine 3/Site 4 - 100 m south of pit.

[b] Value at 3 m above the ground, interpolated from 1.5 and 4.5 m warm wire anemometer data using a logarithmic profile.

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TABLE 7-8. ROAD AND TRAFFIC CHARACTERISTICS - GRADERS

	Road surface properties						
Run	Loading (g/m^2)	Silt (%)	Moist. (%)	Vehicle mix	Mean vehicle speed (km/h)	Mean vehicle weight (tons)	Mean No. of vehicle wheels
K-19	328	23.1	9.1	All graders	8	14	6.0
K-20	535	29.0	8.8	All graders	10	14	6.0
K-21	495	27.8	7.2	All graders	10	14	6.0
K-24	597	17.6	4.0	Mostly graders	10	13	5.9
K-25	776	24.5	5.4	All graders	10	14	6.0
P-16	a	7.2	1.0	Graders	19	14	6.0
P-17	a	7.2	1.0	Graders	16	14	6.0

[a] Sample not analyzed for loading.

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TABLE 7-9. TEST RESULTS FOR HAUL TRUCKS

	Particulate emission rates			
Run[a]	TP, lb/VMT	SP, lb/VMT	IP, lb/VMT	FP, lb/VMT
J-9*	51.4	15.2	7.4	0.41
J-10*	54.1	33.0	17.7	0.54
J-11	67.2	30.2	15.4	0.69
J-12*	16.5	12.9	7.9	0.26
J-20*	36.6	12.3	5.4	0.14
J-21*	76.4	14.2	6.0	0.21
K-1	23.2	8.2	3.3	0.05
K-6	8.0	2.2	1.1	0.07
K-7	4.6	3.9	2.5	0.07
K-8	9.2	2.5	1.3	0.10
K-9	13.4	6.4	3.3	0.15
K-10	18.1	4.4	2.3	0.18
K-11	17.5	4.5	2.3	0.19
K-12	14.3	6.0	3.2	0.23
K-13	2.4	0.60	0.40	0.10
K-26	5.7	3.4	1.8	0.06
L-1	7.9	0.71	0.32	0.02
L-2	b	b	b	b
L-3	76.9	67.2	42.1	1.85
L-4	107	73.1	38.1	0.57

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TABLE 7-9 (continued)

Run[a]	Particulate emission rates			
	TP, lb/VMT	SP, lb/VMT	IP, lb/VMT	FP, lb/VMT
P-1	31.4	20.6	14.7	2.88
P-2	45.0	6.3	3.2	0.29
P-3	43.6	24.1	11.5	0.20
P-4	14.0	5.1	2.2	0.05
P-5	34.2	14.1	6.3	0.14
P-6	5.1	1.8	1.0	0.11
P-7	20.5	8.4	4.1	0.16
P-8	14.6	4.3	2.1	0.10
P-9	16.5	5.6	2.5	0.07

[a] Asterisk indicates comparability run.

[b] Profiler samplers malfunctioned.

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TABLE 7-10. TEST RESULTS FOR LIGHT- AND MEDIUM-DUTY VEHICLES

Run	Particulate emission rates			
	TP, lb/VMT	SP, lb/VMT	IP, lb/VMT	FP, lb/VMT
J-7	a	a	a	a
J-8	0.55	0.35[b]	0.34[b]	0.09[b]
J-13	7.0	5.5[b]	4.5[b]	0.50[b]
J-18	9.5	8.2[b]	6.6[b]	1.5[b]
J-19	7.1	6.7[b]	5.2[b]	0.22[b]
K-2	5.0	0.64	0.33	0.03
K-3	3.1	0.76	0.39	0.03
K-4	3.0	0.60	0.34	0.04
K-5	2.7	0.93	0.52	0.05
P-11	12.8	8.5	4.5	0.10
P-12	12.8	9.0	5.1	0.13
P-13	9.7	7.8	4.1	0.15

[a] Emissions too low to be measured.
[b] ERC dichotomous samplers.

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TABLE 7-11. TEST RESULTS FOR SCRAPERS

Run[a]	Particulate emission rates			
	TP, lb/VMT	SP, lb/VMT	IP, lb/VMT	FP, lb/VMT
J-1*	41.4	8.6	4.2	0.27
J-2*	66.5	9.4	4.0	0.19
J-3*	125	50.2	26.1	1.5
J-4*	27.5	3.9	1.7	0.09
J-5*	96.7	17.7	10.0	1.4
K-15	126	16.2	7.2	0.39
K-16	206	29.2	15.6	1.8
K-17	232	74.3	35.6	1.6
K-18	179	43.0	19.3	0.81
K-22	58.4	10.3	4.8	0.29
K-23	118	24.5	11.1	0.54
L-5	360[b]	355[b]	217[b]	0.72[b]
L-6	184	163	94.0	1.0
P-15	383	c	c	c
P-18	18.8[d]	4.0[d]	1.4[d]	0.02[d]

[a] Asterisk indicates comparability test.
[b] Profiler samplers malfunctioned.
[c] Only one dichotomous sampler and only four good passes.
[d] Only two profilers operational.

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TABLE 7-12. TEST RESULTS FOR GRADERS

Run	Particulate emission rates			
	TP, lb/VMT	SP, lb/VMT	IP, lb/VMT	FP, lb/VMT
K-19	31.3	4.0	2.3	0.33
K-20	29.0	4.3	1.7	0.46
K-21	22.5	1.8	0.89	0.08
K-24	13.1	3.2	1.9	0.29
K-25	19.5	7.3	4.1	0.38
P-16	53.2	34.0	15.4	0.09
P-17	73.9	8.6	2.9	0.04

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The means, standard deviations ,and ranges of SP emission rates for each source category are shown below:

Source	No. tests	SP emission rate (lbs/VMT) Mean	Std. dev.	Range
Haul trucks				
Uncontrolled	19	18.8	20.2	0.71-67.2
Controlled	9	4.88	3.44	0.60- 8.4
Light- and medium-duty vehicles				
Uncontrolled	10	4.16	3.73	0.64- 9.0
Controlled	2	0.35[a]	a	a
Scrapers				
Uncontrolled	14	57.8	95.3	3.9 -355
Graders				
Uncontrolled	7	9.03	11.2	1.8 -34.0

[a] On one of two tests, the emissions were below detectable limits.

As expected, the SP emission rates for controlled road sources were substantially lower than for uncontrolled sources. The mean emission rate for watered haul roads was 26 percent of the mean for uncontrolled haul roads. For light- and medium-duty vehicles, the mean emission rate for roads treated with calcium chloride was 8 percent of the mean for uncontrolled roads.

The average ratios of IP and FP to SP emission rates are:

Source	Average ratio of IP to SP emission rates	Average ratio of FP to SP emission rates
Haul trucks	0.50	0.033
Light- and medium-duty vehicles	0.63	0.112
Scrapers	0.49	0.026
Graders	0.48	0.055

As indicated, SP emission from light- and medium-duty vehicles contained a much larger proportion of small particles than did the other source categories.

The measured dustfall rates are shown in Tables 7-14 through 7-16 for haul trucks, light- and medium-duty vehicles, scrapers, and graders, respectively.

Flux data from collocated samplers are given for the upwind sampling location and for three downwind distances. The downwind dustfall fluxes decay sharply with distance from the source.

PROBLEMS ENCOUNTERED

Adverse meteorology created the most frequent difficulties in sampling emissions from unpaved roads. Isokinetic sampling cannot be achieved with the existing profilers when wind speeds are less than 4 mph. Problems of light winds occurred mostly during the summer testing at Mine 1. In addition, wind direction shifts resulted in source plume impacts on the upwind samplers on several occasions. These events, termed "bad passes," were confined for the most part to summer testing at Mine 1.

Bad passes were not counted in determining source impact on downwind samplers. Measured upwind particualte concentrations were adjusted to mean observed upwind concentrations for adjoining sampling periods at the same site when no bad passes occurred.

Another problem encountered was mining equipment breakdown or reassignment. On several occasions sampling equipment had been deployed but testing could not be conducted because the mining vehicle activity scheduled for the test road did not occur.

TABLE 7-13. DUSTFALL RATES FOR TESTS OF HAUL TRUCKS

	Flux (mg/m^2-min.)			
		Downwind		
Run	Upwind	5 m	20 m	50 m
J-6	16	a	6.1	a
	17	a	d	a
J-9	4.0	131	29	13
	3.9	91	36	6.7
J-10	7.5	126	54	5.2
	5.9	126	45	8.9
J-11	3.3	274	75	16
	1.9	285	56	27
J-12	0.9	19	8.2	1.4
	6.4	14	9.2	3.4
J-20	0.8	31	8.1	10.0
	1.2	33	9.1	7.9
J-21	7.1	19	17	2.0
	19	22	7.6	30
K-1	2.5	34[b]	16	8.0
	3.5	25[b]	51	17
K-6	0.7	12	3.0	2.9
	0.6	12	3.0	4.1
K-7	0.6	12	11	7.2
	0.5	16	12	8.0
K-8	1.6	7.1	8.1	3.7
	5.3	14	1.1	3.1
K-9	2.0	21	6.1	5.2
	6.6	16	7.0	6.2
K-10	0.7[c]	25	25	8.1
	0.8[c]	34	18	8.1
K-11	0.7[c]	33	26	8.2
	0.8[c]	42	18	8.1

(continued)

TABLE 7-13 (continued)

Run	Flux (mg/m²-min.)			
		Downwind		
	Upwind	5 m	20 m	50 m
K-12	0.7[c] 0.8[c]	20 22	24 16	7.6 7.5
K-13	0.3 0.3	6.6 d	1.9 1.6	0.6 d
K-26	0.6 0.7	18 24	2.7 3.0	2.3 2.1
L-1	12 2.4	6.2 9.3	3.7 7.5	0.7 2.5
L-2 L-3 L-4	5.4 3.7	97 61	27 28	10 14
P-1	2.8 3.8	13 24	8.6 6.4	6.0 6.6
P-2	28 2.7	23 20	24 7.6	18 d
P-3	e	e	e	e
P-4	2.2 1.0	b 4.1	3.1 2.2	1.8 1.9
P-5	0.7 0.9	8.0 3.0	4.3 2.7	1.2 4.7
P-6	0.4 0.4	4.3 2.3	4.0 2.2	1.4 4.2
P-7	1.5 0.6	5.9 2.2	1.7 5.7	0.8 1.4
P-8	0.3 1.1	2.3 1.9	0.7 0.6	0.6 0.8
P-9	1.1 4.7	7.8 3.4	0.7 4.1	1.4 1.2

a Negative net weight when blank was included.
b At 10m.
c Same buckets used for K-10, K-11, K-12.
d No final weight.
e Sample not taken.

TABLE 7-14. DUSTFALL RATES FOR TESTS OF LIGHT AND MEDIUM DUTY VEHICLES

Run	Flux (mg/m²-min.)			
		Downwind		
	Upwind	5 m	20 m	50 m
J-7	a a	a a	a a	a a
J-8	3.8 a	2.0 a	0.8[b] a	0.0[c] a
J-13	a a	23 30	3.0 6.5	5.6 2.6
J-18	a 0.7	20 20	0.9 0.2	1.2 1.2
J-19	a a	21 21	3.5 4.2	0.7 1.0
K-2	0.2 0.4	d 22[e]	7.7 6.8	6.1 4.2
K-3	0.2 3.8	d 6.8[e]	6.0 f	5.4 3.7
K-4	0.9 0.4	9.8 14	8.9 9.3	2.9 8.9
K-5	0.9 0.4	9.2 14	8.4 8.8	2.8 8.4
P-11	0.6 0.3	d 47	8.6 4.3	20 3.5
P-12	f f	48 130	11 25	8.1 5.7
P-13	f	f	f	f

[a] Negative net weight when blank was included.
[b] At 18 m.
[c] At 35 m.
[d] No final weight.
[e] At 10 m.
[f] Sample not taken.

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TABLE 7-15. DUSTFALL RATES FOR TESTS OF SCRAPERS

Run	Flux (mg/m^2-min.)			
		Downwind		
	Upwind	5 m	20 m	50 m
J-1	4.8	33	8.5	a
	3.4	32	8.2	a
J-2	51	26	13	b
	54	34	1.3	b
J-3	27	39	b	7.9
	7.1	39	2.7	b
J-4	5.8	14	6.4	1.3
	6.0	12	6.3	6.5
J-5	2.0	16	3.0	2.0
	2.9	12	3.3	1.3
K-15	3.6	84	69	34
	3.9	180	24	360[c]
K-16	11	44	16	52
	9.2	46	13	52
K-17	4.2	3100	370	40
	3.5	2800	490	40
K-18	4.1	860	171	25
	3.5	760	140	25
K-22	0.9	39	21	11
	1.3	34	30	7.3
K-23	0.9	99	53	26
	1.3	87	74	19
L-5	8.1	200	33	6.2
L-6	8.2	100	69	40
P-15	a	a	a	a
P-18	a	a	a	a

a Sample not taken.
b Negative net weight when blank was included.
c Sample included nondust material.

TABLE 7-16. DUSTFALL RATES FOR TESTS OF GRADERS

	Flux (mg/m^2-min.)			
		Downwind		
Run	Upwind	5 m	20 m	50 m
K-19	2.5	46	52	28
	2.6	75	36	18
K-20	2.6	20	53	28
	2.7	25	37	19
K-21	2.6	65	62	34
	2.7	56	43	22
K-24	2.7	64	49	23
	4.5	48	40	16
K-25	2.8	61	46	22
	4.7	46	39	15
P-16	a	22	2.9	0.2
	a	22	9.8	6.6
P-17	a	21	6.1	6.6
	a	27	10	9.9

a Sample not taken.

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SECTION 8

RESULTS FOR SOURCES TESTED BY UPWIND-DOWNWIND SAMPLING

SUMMARY OF TESTS PERFORMED

Five different sources were tested by the upwind-downwind method--coal loading, dozers, draglines, haul roads, and scrapers. However, haul roads and scrapers were tested by upwind-downwind sampling only as part of the comparability study, with the exception of six additional upwind-downwind haul road tests during the winter sampling period. Test conditions, net concentrations, and calculated emission rates for the comparability tests were presented in Section 6. Test conditions and emission rates for haul road tests are repeated here for easier comparison with winter haul road tests, but scraper data are not shown again. Haul roads were tested by the upwind-downwind method during the winter when limited operations and poor choices for sampling locations precluded sampling of dozers or draglines, the two primary choices.

A total of 87 successful upwind-downwind tests were conducted at teh three mines/four visits. They were distributed by source and by mine as follows:

	Number of tests			
Source	Mine 1	Mine 2	Mine 1W	Mine 3
Coal loading	2	8		15
Dozer, overburden	4	7		4
Dozer, coal	4	3		5
Draglines	6	5		8
Haul roads	5		6	
Scrapers	5			

Test conditions for the coal loading tests are summarized in Table 8-1. Correction factors for this source may be difficult to develop: bucket capacities and silt contents did not vary significantly during the tests, nor did drop distances (not shown in the table). One variable not inlcuded in the table was type of coal loading equipment. At the first two mines, shovels were used; at the third mine, front-end loaders were used.

TABLE 8-1. TEST CONDITIONS FOR COAL LOADING

Test	Date	Start time	Sampling duration, minutes	Source characteristics		Soil properties		Meteorological conditions		
				No. of trucks	Bucket capacity, yd^3	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
Mine 1										
1	8/11/79	12:35	43	10	17	No data	22	87	1.0	A
2	8/11/79	13:45	39	3	17		22	91	1.0	A
Mine 2										
1	10/16/79	9:45	72	4	14	No data	38	46	4.3	C
2	10/16/79	12:45	80	4	14		38	55	4.3	C
3	10/16/79	16:00	45	4	14		38	56	2.9	C
4	10/16/79	17:00	30	3	14		38	56	2.6	C
5	10/18/79	9:40	42	3	14		38	50	2.1	C
6	10/18/79	12:50	40	2	14		38	57	4.8	D
7	10/18/79	15:30	36	2	14		38	60	4.9	D
8	10/30/79	16:00	35	5	16		38	38	5.0	C
Mine 3										
1	7/26/80	8:34	35	2	16	3.6	11.9	74	1.7	C
2	7/26/80	9:26	44	3	16	3.6	11.9	80	1.0	A
3	7/26/80	10:27	24	2	16	3.6	11.9	82	1.0	A
4	7/30/80	10:35	23	4	16	4.2	18.0	94	1.1	A
5	7/30/80	11:50	52	10	16	4.2	18.0	95	1.1	A
6	7/30/80	12:58	65	8	16	4.2	18.0	95	2.9	B
7	8/05/80	10:15	54	2	16	3.9	12.2	93	1.3	B
8	8/07/80	9:17	34	3	16	4.0	11.1	82	1.0	C
9	8/07/80	10:02	46	2	16	4.0	11.1	83	1.3	D
10	8/07/80	12:00	28	3	16	4.0	11.1	100	1.2	B
11	8/07/80	12:48	47	4	16	4.0	11.1	100	1.9	A
12	8/12/80	8:42	22	4	16	3.7	6.6	79	2.0	C
13	8/12/80	10:03	18	2	16	3.7	6.6	89	1.9	C
14	8/12/80	10:42	13	3	16	3.7	6.6	89	1.8	C
15	8/12/80	11:30	22	3	16	3.7	6.6	89	2.5	D

Test conditions for dozers are summarized in Tables 8-2 and 8-3 for dozers working overburden and coal, respectively. These two source categories exhibited a wide range of operating and soil characteristics in their tests--speed varied from 2 to 10 mph, silt contents from 3.8 to 15.1 percent, and moisture contents from 2.2 to 22 percent. This indicates a good potential for correction factors. Also, there is a possibility of producing a single emission factor for the two dozer operations.

Dragline test conditions are shown in Table 8-4. Bucket sizes for the different tests were all nearly the same, but large differences in drop distances (5 to 100 ft), silt contents (4.6 to 14 percent), and moisture contents (0.2 to 16.3 percent) were obtained. One dragline variable used in the preliminary data analysis for the statistical plan, operator skill, was not included in Table 8-4 because it was judged to be too subjective and of little value as a correction factor for predicting emissions from draglines. Also, it was not found to be a significant variable in the preliminary data analysis.

Test conditions for haul roads tested by upwind-downwind sampling are summarized in Table 8-5. Most of the tests for this source were done by exposure profiling, so this subset of tests was not analyzed separately to develop another emission factor. Instead, the calculated emission rates and test conditions for these tests were combined with the exposure profiling test data in the data analysis and emission factor development phase.

RESULTS

The apparent TSP emission rates calculated from the concentrations at each hi-vol sampler are shown in Tables 8-6 through 8-10 for coal loading, dozers (overburden), dozers (coal), draglines, and haul roads, respectively. These reported emission rates have not been adjusted for any potential correction factors. The individual emission rates are shown as a function of source-sampler distances in these tables. Distance is an important factor in the evaluation of deposition.

When the samples were evaluated for deposition as described in Section 5, only 21 out of the 87 upwind-downwind samples (including scrapers) demonstrated distinct fallout over the three or four distances. The percentage of tests showing fallout was much higher for sources sampled as line sources than for sources samples as point sources: 13 out of 25 (52 percent) for line sources compared to 8 out of 62 (12.9 percent) for point sources.

It was concluded that some problem exists with the point source dispersion equation because its results rarely indicate

TABLE 8-2. TEST CONDITIONS FOR DOZER (OVERBURDEN)

Test	Date	Start time	Sampling duration, minutes	Source characteristics		Soil properties		Meteorological conditions		
				Speed, mph	Passes	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
Mine 1										
1	8/22/79	13:10	59	4	30	15.1	8.8	79	2.9	B
2	8/22/79	14:30	63	4	32	15.1	8.8	86	1.8	A
3	8/22/79	16:15	71	2	17	15.1	8.8	79	3.2	B
4	8/23/79	13:25	133	2	33	7.5	8.2	80	2.0	A
Mine 2										
1	10/15/79	11:00	46	7	20	4.1	16.8	65	5.0	D
2	10/20/79	12:45	64	7	42	3.8	15.6	44	8.5	D
3	10/23/79	13:00	97	7	52	4.4	15.3	42	4.9	C
4	10/23/79	15:05	54	7	22	4.4	15.3	51	3.2	B
5	10/23/79	16:20	55	7	7	4.4	15.3	52	1.8	C
6	10/27/79	12:50	145	7	82	5.4	13.6	53	3.3	C
7	10/27/79	16:08	55	7	60	5.4	13.6	65	2.7	C
Mine 3										
1	7/29/80	8:28	60	2	30	7.0	3.6	78	1.5	A
2	7/29/80	9:54	43	2	21	7.0	3.6	85	1.3	B
3	8/11/80	9:24	49	2	14	6.9	2.2	83	1.1	A
4	8/11/80	12:30	23	2	10	6.9	2.2	85	1.9	B

TABLE 8-3. TEST CONDITIONS FOR DOZER (COAL)

Test	Date	Start time	Sampling duration, minutes	Source characteristics			Soil properties		Meteorological conditions		
				Speed, mph	Passes	No. of dozers	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
Mine 1											
1	8/18/79	10:15	60	8	n/a	2	8.0	20.0	83	1.5	A
2	8/18/79	12:45	46	8	n/a	2	8.0	20.0	86	3.4	B
3	8/18/79	13:50	37	8	n/a	1	8.0	20.0	88	2.3	B
4	8/18/79	14:50	30	8	n/a	1	8.0	20.0	85	2.2	B
Mine 2											
1	10/26/79	14:20	25	7	24	2	6.0	22.0	53	3.6	C
2	10/26/79	15:00	47	7	22	1	6.0	22.0	53	4.1	D
3	10/26/79	16:08	43	7	26	1	6.0	22.0	54	2.7	C
Mine 3											
1	8/10/80	16:02	15	8	17	1	11.3	4.0	92	5.7	C
2	8/10/80	16:40	17	10	21	1	11.3	4.0	93	6.0	D
3	8/10/80	17:25	12	12	19	1	11.3	4.0	95	5.2	D
4	8/10/80	18:05	18	5	19	1	11.3	4.0	91	3.8	C
5	8/10/80	18:45	14	5	15	1	11.3	4.0	90	3.0	C

TABLE 8-4. TEST CONDITIONS FOR DRAGLINES

Test	Date	Start time	Sampling duration, minutes	Source characteristics			Soil properties		Meteorological conditions		
				Buckets	Bucket capacity, yd³	Drop dist, ft	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
Mine 1											
1	8/08/79	11:15	49	32	60	10	6.4	8.4	78	2.4	B
2	8/08/79	14:09	62	46	60	32	6.4	8.4	83	3.1	B
3	8/08/79	16:40	60	44	60	20	6.4	8.4	88	3.9	C
4	8/17/79	11:00	44	54	60	28	6.4	8.4	84	2.0	A
5	8/17/79	14:40	49	49	60	30	6.4	8.4	86	1.0	A
6	8/17/79	16:00	31	5	60	82	6.4	8.4	84	1.8	A
Mine 2											
1	10/13/79	12:15	68	63	32	40	11.4	15.6	47	4.7	D
2	10/13/79	14:28	72	71	32	40	11.4	15.6	52	4.1	C
3	10/13/79	16:00	74	66	32	5	11.4	15.6	53	3.6	C
4	10/21/79	12:48	52	46	32	10	12.6	16.3	38	3.9	D
5	10/24/79	14:45	83	6	32	30	5.0	14.9	54	2.7	C
Mine 3											
1	7/31/80	10:19	41	30	55	100	14.0	2.7	85	1.0	A
2	7/31/80	11:35	53	37	55	60	14.0	2.7	93	1.9	A
3	7/31/80	12:40	35	40	55	100	14.0	2.7	94	2.2	B
4	7/31/80	13:28	55	22	55	30	4.6	1.2	96	2.1	B
5	8/02/80	10:30	29	22	65	10	5.0	0.2	88	6.2	D
6	8/02/80	11:35	40	24	65	20	5.0	0.2	88	7.4	D
7	8/02/80	12:34	26	18	65	25	5.0	0.2	88	4.1	C
8	8/02/80	13:45	55	23	65	25	5.0	0.2	90	3.6	C

TABLE 8-5. TEST CONDITIONS FOR HAUL ROADS

Test	Date	Start time	Sampling duration, minutes	Source characteristics			Soil properties		Meteorological conditions		
				Passes	Mean speed, mph	Mean weight, ton	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
Mine 1											
J9	8/01/79	10:21	59	44	19	72	9.4	3.4	83	3.8	B
J10	8/01/79	14:02	47	43	19	66	9.4	2.2	89	4.8	C
J12	8/02/79	10:47	49	20	15	109	14.2	6.8	81	1.1	A
J20	8/09/79	14:10	46	23	17	138	11.6	8.5	73	2.1	B
J21	8/09/79	16:52	21	13	15	121	11.6	8.5	77	2.2	B
Mine 1W											
1	12/04/79	10:54	64	14					64	5.7	D
2	12/08/79	12:40	38	28	24	106	15.9[a]	5.0[a]	53	6.2	D
3	12/08/79	13:50	54	24	20	118	13.8	4.9	56	5.8	D
4	12/08/79	15:00	52	31	20	95	18.0	5.1	56	5.4	D
5	12/09/79	9:15	55	25					52	2.0	C
6	12/09/79	10:30	63	22					59	5.0	D

[a] Average of other samples this day.

TABLE 8-6. APPARENT EMISSION RATES FOR COAL LOADING
High-Volume (30 μm)

Test No.	Apparent emission rates at specified distances, lb/ton									Distances from source, m			
	First		Second			Third			Fourth				
Mine 1													
1	0.006	0.005	0.005	0.005	0.006	0.008	0.010	0.010		25	50	80	
2	0.005	0.004	0.010	0.008	0.010	0.017	0.016	0.031		20	45	75	
Mine 2													
1	0.030	0.057	0.050	0.048	0.034	0.043	0.081	0.045		34	65	131	
2	0.043	0.089	0.071	0.121	0.067	a	a	a		65	96	162	
3	0.014	0.023	0.019	0.017	0.011	0.017	0.045	0.002		57	82	183	
4	0.013	0.018	0.013	0.012	0.010	0.016	0.026	0.012		80	105	206	
5	0.005	0.007	0.007	0.008	0.015	0.004	0.013	0.017	0.013	30	62	101	199
6	0.022	0.025	0.039	0.012	0.021		0.013	0.017	0.033	10	28	62	170
7	0.030	0.008	0.011	0.018	0.038		0.012		0.027	10	28	62	170
8	0.005	0.004	0.005	0.004	0.005	0.009	0.010	0.010		30	60	110	
Mine 3													
1	0.128	0.113	0.168	0.038	0.072	0.088		0.015	0.025	111	132	148	166
2	0.115	0.049	0.008	0.061	0.043	0.053	0.036	0.043	0.055	31	58	96	150
3	0.060	0.067	0.055	0.038	0.035	0.056	0.057	0.051	0.042	29	56	94	148
4	0.005		0.016	0.011	0.012	0.019		0.009	0.010	12	24	31	45
5	0.006	0.005	0.007	0.007	0.013	0.014			0.019	16	27	34	50
6	0.008	0.014	0.010	0.016	0.021	0.015			0.029	16	27	34	50
7		0.005	0.026	a	0.041	0.036	0.056	0.017		10	20	35	
8	0.041	0.051	0.069	0.070		0.079	0.104			60	90	130	
9	0.042	0.047	0.059	0.064		0.066	0.070			45	75	115	
10	0.194	0.100	0.200	0.133		0.214	0.222			45	65	105	
11	0.041	0.029	0.130	0.045		0.191	0.134			29	49	89	
12	0.039	0.034	0.049	0.051		0.036	0.077			35	65	95	
13	0.364	0.842	0.912	1.271		1.218	1.214			35	65	95	
14	0.165	0.282	0.291	0.356		0.352	0.507			35	62	92	
15	0.177	0.161	0.131	0.128		0.265	0.267			35	62	92	

[a] Interference from truck traffic.

TABLE 8-7. APPARENT EMISSION RATES FOR DOZER (OVERBURDEN)
High-Volume (30 μm)

Test No.	Apparent emission rates at specified distances, lb/h										Distances from source, m			
	First		Second			Third			Fourth					
Mine 1														
1	14.3	18.2	11.6	9.0	7.8	10.3	10.5	a	4.5		15	44	78	180
2	12.0	13.0	17.0	17.9	7.9	22.2	15.7	8.9	8.2		20	49	83	185
3	2.5	2.6	2.3	0.8	3.2	1.8	a	2.4	1.5		25	54	88	190
4	3.4	5.5	4.9	1.3	2.3	0.6	a	8.1	13.1		25	52	78	138
Mine 2														
1	0.8	0.3	2.0	0.6	6.1						25	56		
2	2.1	0.6	a	0.7		3.0	2.4	1.8	5.3		20	46	81	151
3	1.8	2.2	2.3	1.8	2.1	3.7	3.5	3.5	6.3		25	58	100	162
4	3.0	2.9	0.8	0.0	1.9	0.0	0.0	0.0	3.2		25	58	100	162
5		1.6	4.8	0.0	3.6	8.6	17.3	19.8	17.6		25	58	100	162
6	0.8	0.7	0.8	0.4		1.2			2.4	2.7	8	23	53	103
7	1.0	1.5	0.7	1.3		1.5	3.5		0.0	1.0	31	66	90	146
Mine 3														
1	4.5	5.2	4.6	5.5	8.0	3.8	7.0	8.8	4.8		25	45	75	115
2	2.5	4.8	5.0	4.3	5.0	6.4	4.9	5.0	6.3		20	40	70	110
3	21.0	14.9	18.0	17.8		14.4	16.7				25	41	63	
4	25.9		20.1	15.9		17.7	23.9				43	59	81	

[a] Used as upwind concentration.

TABLE 8-8. APPARENT EMISSION RATES FOR DOZER (COAL)
High-Volume (30 μm)

Test No.	Apparent emission rates at specified distances, lb/h										Distances from source, m			
	First		Second			Third			Fourth					
Mine 1														
1	13.4	16.7	12.1	15.4	20.1	16.8	14.1	23.5	20.4		125	155	193	292
2	47.1	34.9	40.9	34.3	23.1	34.8	50.8	37.9	a		125	155	193	292
3	8.3	38.5	12.1	12.5	19.0	b	31.2	45.0	11.6		125	155	193	292
4	11.9	22.0	16.5	25.0	30.8	b	18.4	46.8	24.3		125	155	193	292
Mine 2														
1	9.7	8.0	10.4	8.6	6.4	11.5	13.4				30	42	53	
2	3.0	5.8	5.2	6.6	8.4	4.6	9.5				40	67	78	
3	1.6	2.5	3.8	3.4	4.2	1.0	4.4				40	67	78	
Mine 3														
1	281		284	303		229	340		283	300	30	60	91	133
2	298	234	217	153		164	217		250	242	30	60	91	133
3	300	453	533	427		540	540		526	670	30	60	91	133
4	255	255	324	368		306	414		366	293	30	60	91	133
5	160	152	243	193		239	245		300	261	30	60	91	133

[a] Less than upwind concentration.
[b] Used as upwind concentration.

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TABLE 8-9. APPARENT EMISSION RATES FOR DRAGLINE
High-Volume (30 μm)

Test No.	Apparent emission rates at specified distances, lb/yd³									Distances from source, m			
	First		Second			Third			Fourth				
Mine 1													
1	0.023	0.023	0.023	0.021	0.021	0.023	0.028	0.039	0.028	60	90	130	220
2	0.009	0.010	0.021	0.022	0.023	0.050	0.043	0.054	0.068	20	50	90	180
3	0.003	0.005	0.001	0.007	0.003	0.003	0.003	0.009	0.007	20	50	90	180
4	0.042	0.055	0.032	0.051	0.051	0.016	0.031	0.060	0.007	90	122	156	246
5	0.074	0.067	0.073	0.074	0.074	0.046	0.062	0.107	0.026	140	172	206	296
6	0.355	0.446	0.314	0.302	0.442	0.047	0.049	0.197	a	80	112	146	236
Mine 2													
1	0.034	0.052	0.043			0.068	0.025	0.024	0.046	40	67	97	203
2	0.019	0.026	0.031	0.016	0.024	0.039	0.017	0.035	0.027	31	61	89	168
3	0.001	0.002	0.004	0.001	0.001	0.005	0.003	0.002	0.005	31	61	89	168
4	0.012	0.012	0.019	0.016	0.019	0.021	0.017	0.013	0.025	150	177	216	310
5	0.065	0.071	0.061	0.035	0.014	0.025	0.033	0.030	0.000	110	139	172	230
Mine 3													
1	0.188	0.181	0.142	0.138	0.138	0.120		0.077	0.067	94	121	148	
2	0.122	0.142	0.102	0.120	0.202	0.204	0.181	0.130		94	121	148	
3	0.196	0.205	0.185	0.179	0.191	0.246	0.194	0.192		94	121	148	
4	0.080	0.062	0.111	0.102	0.115	0.157	0.021	0.125		94	121	148	
5	0.063	0.057	0.064	0.053	0.066	0.056	0.052	0.067		140	166	196	
6	0.081	0.070	0.065	0.049	0.072	0.069	0.069	0.134	0.138	98	124	154	234
7	0.122	0.075	0.079	0.131	0.087	0.101	0.088	0.114	0.136	98	124	154	234
8	0.101	0.097	0.103	0.113	0.106	0.101	0.111	0.105	0.104	140	166	196	276

[a] Concentration less than upwind.

TABLE 8-10. APPARENT EMISSION RATES FOR HAUL ROADS
High-Volume (30 µm)

Test No.	Apparent emission rates at specified distances, lb/VMT								Distances from source, m			
	First		Second		Third		Fourth					
Mine 1												
J9	16.1	12.1	10.8	16.5	12.3	10.3	3.8	6.4	5	20	50	100
J10	13.0	11.1	9.3	8.2	3.2	3.3	a	a	5	20	50	100
J12	3.5	3.5	4.3	4.4	3.1	2.7	1.1	a	5	20	50	100
J20	5.1	7.7	4.0	4.6	2.8	2.8	a	a	5	20	50	100
J21	11.7	18.4	11.8	15.8	8.7	16.8	6.8	10.2	5	20	50	100
Mine 1W												
1	11.6	11.6	12.1	9.6	13.6	13.1	13.9	14.6	5	20	50	80
2	19.1	13.1	13.3		13.3	11.2	8.5	10.6	5	20	50	80
3	28.3	21.8	15.6	15.2		7.7	4.5	4.8	5	20	50	80
4	36.0	38.3	32.8	21.6	29.8	25.6	20.0	21.7	5	20	50	80
5	11.5	15.1	9.3	14.4		13.9	6.3		5	20	50	80
6	47.8	40.9	31.1	31.0		31.5	28.8	40.6	5	20	50	80

[a] Downwind concentration less than calculated upwind.

deposition, although the same type and size distribution of emissions are involved as with the line source dispersion equation. The sensitivity of calculated emission rates to several inputs to the point source equation (such as initial plume width, initial horizontal dispersion, distance from plume centerline, and stability class) were examined, but no single input parameter could be found that would change the emission data by distance to show deposition.

The single-value TSP emission rates for each test determined from the multiple emission rate values are summarized in Table 8-11. The means and standard deviations for these tests are shown below:

Source	No. tests	Units	Mean	Std dev	Range
Coal loading	25	lb/ton	0.105	0.220	0.0069-1.09
Dozer, overburden	15	lb/h	6.8	6.9	0.9-20.7
Dozer, coal	12	lb/h	134.3	155.6	3.0-439
Dragline	19	lb/yd^3	0.088	0.093	0.003-0.400
Haul road	11	lb/VMT	17.4	10.9	3.6-37.2
Scraper	5	lb/VMT	18.1	11.4	5.7-35.6

It should be emphasized that the mean values reported here are not emission factors; they do not have any consideration of correction factors included in them.

Emission rates for coal loading varied over a wide range, from 0.0069 to 1.09 lb/ton. Rates at the third mine averaged an order of magnitude higher than at the first two mines. Since a front-end loader was used at the third mine and shovels at the first two, the wide differences in average emission rates may indicate that separate emission factors are required for these two types of coal loading.

Emissions from dozers working overburden varied over a moderate range. Much of that variation can probably be explained by the soil characteristics of the overburden being regraded: soil at the second mine, which in general had the lowest emission rates, had the highest moisture contents and lowest silt contents; soil at the third mine, which had the highest emission rates, was driest. The evaluation of these two correction parameters is described in Section 13.

Coal dozer emissions were grouped very tightly by mine. The averages, standard deviations, and ranges by mine show this:

TABLE 8-11. EMISSION RATES FOR UPWIND-DOWNWIND TESTS

Coal loading		Dozer, overburden		Dozer, coal		Dragline		Haul road/scraper	
Test No.	Emission rate, lb/ton	Test No.	Emission rate, lb/h	Test No.	Emission rate, lb/h	Test No.	Emission rate, lb/yd^3	Test No.	Emission rate, lb/VMT
								Haul road	
Mine 1		Mine 1		Mine 1		Mine 1		Mine 1	
1	0.0069	1	16.2	1	16.1	1	0.024	J9	14.1
2	0.0100	2	12.6	2	40.1	2	0.029	J10	12.0
Mine 2		3	2.6	3	19.0	3	0.004	J12	3.6
1	0.044	4	3.0	4	21.3	4	0.048	J20	6.4
2	0.068	Mine 2		Mine 2		5	0.070	J21	15.0
3	0.0147	1	0.9	1	9.1	6	0.400	Mine 1W	
4	0.0134	2	1.8	2	6.2	Mine 2		1	12.9
5	0.0099	3	2.6	3	3.0	1	0.042	2	16.1
6	0.0228	4	1.3	Mine 3		2	0.026	3	25.0
7	0.0206	5	9.2	1	289	3	0.003	4	37.2
8	0.0065	6	1.0	2	222	4	0.016	5	12.8
Mine 3		7	1.0	3	439	5	0.068	6	36.0
1	0.120	Mine 3		4	323	Mine 3		Scraper	
2	0.082	1	5.4	5	224	1	0.184	Mine 1	
3	0.051	2	5.2			2	0.133	J1	10.6
4	0.0105	3	18.0			3	0.192	J2	18.6
5	0.0087	4	20.7			4	0.099	J3	35.6
6	0.0140					5	0.060	J4	5.7
7	0.035					6	0.068	J5	20.0
8	0.062					7	0.104		
9	0.058					8	0.105		
10	0.193								
11	0.095								
12	0.042								
13	1.09								
14	0.358								
15	0.188								

Mine	Mean	Std dev	Range
1	24.1	10.9	16.1-40.1
2	6.1	3.0	3.0- 9.1
3	299	89.2	222-439

Coal characteristics are also expected to explain part of this variation, but it is doubtful that the very high emission rates at the third mine can be explained with just those parameters. Dozers working coal had considerably higher emission rates than dozers working overburden. The two sources probably cannot be combined into a single emission factor with available data unless some correction parameter reflecting the type of material being worked is incorporated.

Dragline emissions had greater variation within each mine than between mine averages. As with several of the other sources, emission rates at the third mine were highest and moisture contents of soil samples were the lowest. The only sample more than two standard deviations away from the mean was a 0.400 value obtained at the first mine. This potential outlier (its high value may be explained by correction parameters) was more than twice the next highest emission rate.

Haul roads had relatively little variation in emission rates for the tests shown. However, all these tests were taken at the same mine during two different time periods. For a more comprehensive listing of haul road emission rates from all three mines/four visits, the exposure profiling test data in Section 7 should be reviewed.

Average IP and FP emission rates for each test, along with IP emission rates calculated from each sampler, are presented by source in Tables 8-12 athrough 8-16. The values could be averaged without first considering deposition because dichotomous samplers were only located at the first two distances from the source (leaving only about a 30 m distance in which measureable deposition could occur) and because smaller particles do not have significant deposition. Although the IP data from the upwind-downwind tests have a large amount of scatter, no reduction in emission rates with distance is evident.

The average ratios of IP and FP to TSP emission rates are:

Source	Av ratio of IP to TSP emission rates	Av ratio of FP to TSP emission rates
Coal loading	0.30	0.030
Dozer, overburden	0.86	0.196
Dozer, coal	0.49	0.031
Dragline	0.32	0.032
Haul road	0.42	0.024

TABLE 8-12. EMISSION RATES FOR COAL LOADING
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP emission rates at specified distances, lb/ton					Avg IP emis rate, lb/ton	Avg FP emis rate, lb/ton	Dist from source, m	
	First		Second						
Mine 1									
1	0.002	0.001	0.002	0.001	0.002	0.002	0.0001	25	50
2	0.001	0.001	0.002	0.007	0.006	0.003	0.0002	20	45
Mine 2									
1	0.005	0.006	0.002	0.005		0.005	0.0002	34	65
2	0.013	0.050	0.018	0.009		0.022	0.0008	65	96
3	0.003	0.002	0.005	0.003		0.003	0.0001	57	82
4	0.002	0.008	0.005	0.005		0.005	0.0018	80	105
5	0.001	0.004	0.002		0.008	0.004	0.0007	30	62
6	0.005	0.011	0.039		0.014	0.017	0.0029	10	28
7	0.013	0.001	0.005		0.011	0.008	0.0008	10	28
8	0.004	0.003			0.005	0.004	0.0002	30	60
Mine 3									
1	0.112	0.035	0.023	0.006	0.004	0.044	0.0038	111	132
2			0.011		0.005	0.008	0.0005	31	58
3	0.003	0.008	0.039			0.016	0.0022	29	56
4	0.001		0.001	0.004	0.001	0.002	0.0002	12	24
5	0.001	0.001	0.001		0.003	0.001	0.0001	16	27
6	0.002	0.009	0.011		0.003	0.006	0.0001	16	27
7		0.002	0.011		0.012	0.008	0.0012	10	20
8	0.011	0.000	0.018	0.020		0.012	0.0012	60	90
9	0.012	0.012	0.021	0.013		0.014	0.0005	45	75
10	0.051	0.029	0.040	0.036		0.038	0.0033	45	65
11	0.003	0.011	0.056	0.009		0.020	0.0005	29	49
12	0.012	0.006	0.015	0.010		0.011	0.0021	35	65
13	0.575	0.182	0.404	0.352		0.378	0.0054	35	65
14	0.116	0.093	0.152	0.122		0.121	0.0035	35	62
15	No dichot data for test								

TABLE 8-13. EMISSION RATES FOR DOZER (OVERBURDEN)
Dichotomous (15 µm, 2.5 µm)

Test No.	Apparent IP emission rates at specified distances, lb/h					Avg IP emis rate, lb/h	Avg FP emis rate, lb/h	Distances from source, m		
	First		Second							
Mine 1										
1	3.39	1.75	2.43	2.71	5.66	3.18	0.436	15	44	
2	1.68	2.78	2.02	2.22		2.18	0.322	20	49	
3	3.86[a]	1.58	3.18[a]	3.17[a]	2.48	2.85	1.010	25	54	
4	b	b	b	b	b	c	c	25	52	
Mine 2										
1	0.0	0.91[d]	1.13		6.43[d]	2.12	0.583	25	56	
2	3.74[e]	13.9[e]			0.0	5.88	0.091	20	46	
3	2.39[f]	0.0	1.62		0.0	1.00	0.790	25	58	
4	0.846	0.0	0.561		0.521	0.48	0.065	25	58	
5	0.0	4.19[g]	0.375		0.0	1.14	0.680	25	58	
6	1.00[h]	0.922[h]	0.632	0.129		0.68	0.421	8	23	
7	0.885	0.513	2.82[i]	0.646		1.22	0.536	31	66	
Mine 3										
1	0.488	0.679	0.842		1.91	0.98	0.356	25	45	
2	0.701	0.912	0.600		0.913	0.781	0.089	20	40	
3	6.48		5.22		2.00[j]	4.57	0.925	25	41	63
4[k]	33.4		32.6		31.8[l]	32.6	1.73	43	59	81

[a] This dichotomous sampler value could not be corrected to a 15 µm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 16.2 µm.

[b] Downwind concentration less than upwind.

[c] Insufficient data.

[d] See footnote a; represents 13.4 µm cut point.

[e] See footnote a; represents 10.4 µm cut point.

[f] See footnote a; represents 13.5 µm cut point.

[g] See footnote a; represents 20.2 µm cut point.

[h] See footnote a; represents 16.0 µm cut point.

[i] See footnote a; represents 17.4 µm cut point.

[j] Actually at 63 m distance.

[k] See footnote a; represents 19.8 µm cut point.

[l] Actually at 8 m distance.

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TABLE 8-14. EMISSION RATES FOR DOZER (COAL)
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP emission rates at specified distances, lb/h					Avg IP emis rate, lb/h	Avg FP emis rate, lb/h	Dist from source, m	
	First		Second						
Mine 1									
1	3.94	3.94	4.18	3.89	6.97	4.49	0.243	125	155
2	38.0	42.0[a]	67.2[a]	21.1	31.2[a]	39.9	0.730	125	155
3	7.91	1.49	2.44	3.89	7.94	4.73	1.000	125	155
4	6.49	6.48	11.5	13.4	27.0	13.0	2.68	125	155
Mine 2									
1	1.73	3.58	1.02		2.71	2.26	0.252	30	42
2	2.08	1.03	2.94		2.98	2.26	0.199	40	67
3	0.82	0.43	0.57		1.86	0.92	0.138	40	67
Mine 3									
1	214		96	222		177	3.50	30	60
2	254	223	119	113		178	2.25	30	60
3	229	273	259	185		236	4.49	30	60
4	161	157	183	204		176	3.28	30	60
5	70	78	109	72		82.2	3.50	30	60

[a] This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 15.8 μm.

TABLE 8-15. EMISSION RATES FOR DRAGLINE
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP emission rates at specified distances, lb/yd^3					Avg IP emis rate, lb/yd^3	Avg FP emis rate, lb/yd^3	Dist from source, m	
	First		Second						
Mine 1									
1	0.008	0.004	0.002	0.006	0.010	0.006	0.0009	60	90
2	0.008	0.004	0.008	0.021	0.021	0.012	0.0002	20	50
3	0.001	0.001	0.002	0.004	0.002	0.002	0.0001	20	50
4	0.007	0.007	0.003	0.008	0.007	0.006	0.0001	90	120
5	0.010	0.006	0.016	0.025	0.021	0.016	0.0009	140	170
6	0.060	0.038	0.060	0.042	0.104	0.061	0.0087	80	110
Mine 2									
1	0.002	0.003	0.003			0.003	0.0002	40	67
2	0.009	0.009	0.002		0.008	0.007	0.0008	31	61
3	0.001	0.001	0.002		0.001	0.001	0.0003	31	61
4	0.026	0.010	0.005		0.020	0.015	0.0010	150	177
5	0.022	0.028	0.038		0.052[a]	0.035	0.0110	110	139
Mine 3									
1	0.008	0.028	0.015		0.024	0.018	0.0017	94	121
2	0.013	0.017	0.017		0.017	0.016	0.0011	94	121
3	0.058	0.052			0.063	0.058	0.006	94	121
4	0.044	0.063[b]	0.039		0.026	0.043	0.005	94	121
5	0.038	0.055	0.034		0.025	0.038	0.0001	140	166
6	0.034	0.029	0.011		0.040	0.028	0.0017	98	124
7	0.036	0.022	0.019		0.020	0.024	0.0023	98	124
8	0.028	0.003	0.014		0.023	0.017	0.0004	140	166

[a] This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 17.4 μm.

[b] See footnote a; represents 19.0 μm cut point.

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TABLE 8-16. EMISSION RATES FOR HAUL ROADS
Dichotomous (15 μm, 2.5 μm)

Test No.	Apparent IP emission rates at specified distances, lb/VMT						Avg IP emis rate, lb/VMT	Avg FP emis rate, lb/VMT	Distances from source, m		
	First		Second		Third						
Mine 1											
J9	8.71	5.61	5.65	12.13	3.74	5.08	6.82	0.141	5	20	50
J10	7.42	4.50	7.91	7.24	3.55[a]	6.17[a]	6.13	0.300	5	20	50
J12	0.74	0.52	1.50	0.96	0.00	0.53	0.71	0.095	5	20	50
J20	3.81	3.80	5.63[b]	5.83[b]	5.37[b]	8.92[b]	5.56	0.401	5	20	50
J21	5.22	7.41	5.26	5.72	5.65	7.01	6.04	0.758	5	20	50
Mine 1W											
1	4.28	5.91	7.32	6.59			6.02	0.192	5	20	
2	7.18	11.69	9.11				9.33	0.062	5	20	
3	17.12	13.33	8.57	8.97			12.00	0.804	5	20	
4	5.41	3.80	8.06	4.62			5.47	0.620	5	20	
5	2.26	1.57	1.00	1.42			1.56	0.217	5	20	
6	10.78	12.36	10.25	14.36			11.94	0.165	5	20	

[a] This dichotomous sampler value could not be corrected to a 15 μm cut point to reflect the wind speed bias of the sampler inlet. The uncorrected cut point is about 13.6 μm.

[b] See footnote a; represent 19.0 μm cut point.

These values are different than the average ratios of net concentrations because of the effect of deposition on calculation of the single-value TSP emission rates.

The overburden dozer IP/TPS ratios are much higher than for other sources because five of the 15 tests had IP concentrations much higher than TSP concentrations. When the IP concentration exceeds the TSP concentration, correction of the IP value to 15 um size from the actual (wind speed dependent) cut point cannot be performed by the method described on Page 83. For such cases in Table 8-13 (and Table 8-14 through 8-16), the uncorrected IP value were reported along with their estimated cut points. If the five tests with uncorrected IP data were eliminated, the average IP/TSP ratio would be 0.28, much closer to that other sources. No explanation was found for the high IP concentrations compared to TPS concentrations for overburden dozers.

For all sources except overburden dozers, the IP and FP emission rate variabilities (as measured by the relative standard deviation) were about the same as TSP emission rate variabilities. Due to the four high dichotomous sample values, the IP and FP emission rates for overburden dozers had about twice the relative standard deviation as the TSP emission rates.

PROBLEMS ENCOUNTERED

The most common problem associated with upwind-downwind sampling was the long time required to set up the complex array of 16 samplers and auxiliary equipment. On many occasions, the wind direction would change or the mining operation would move while the samplers were still being set up.

Another frequent problem was mining equipment breakdown or reassignment. At various times, the sampling team encountered these situations: pwer loss to dragline; front-end loader broke down while loading first truck; dozer broke down, 2 hours until replacement arrived; dozer operator called away to operate frontend loader; and brief maintenance check of dragline leading to shutdown for the remainder of shift for repair.

A third problem was a typical operation of the mining equipment dragline sampling. One example was the noticeable difference in dragline operators' ability to lift and swing the bucket without losing material. Sampling of a careless operator resulted in emission rates two to five times as high as the previous operator working in the same location.

The dragline presented other difficulties in sampling by the upwind-downwind method. For safety reasons or because of topographic obstructions, it was often impossible to place samplers in a regular array downwind of the dragline. Therefore, many samples were taken well off the plume centerline, resulting in large adjustment factor values in the dispersion equation calculations and the potential for larger errors. Estimating average source-to-sampler distances for moving operations such as draglines was also difficult.

Sampling of coal loading operations was complicated by the many related dust-producing activities that are associated with it. It is impossible to sample coal loading by the upwind-downwind method without also getting some contributions from the haul truck pulling into position, form a frontend loader cleaning spilled coal from the loading area, and from the shovel or frontend loader restacking the loose coal between trucks. It can be argued that all of these constitute necessary parts of the overall coal loading operation and they are not a duplication of emissions included in other emission factors, but the problem arises in selecting loading operations that have typical amounts of this associated activity.

Adverse meteorology also created several problems in obtaining samples. Weather-related problems were not limited to the upwind-downwind sampling method or the five sources samples by this method, but the large number of upwind-downwind tests resulted in more of these test periods being impacted by weather. Wind speed caused problems most frequently. When wind speeds were less than 1 m/s or greater than about 8 m/s, sampling could not be done. Extremely low and high winds occurred on a surprisingly large number of days, causing lost work time by the field crew, delays in starting some tests, and premature cessation of others. Variable wind directions and wind shifts were other meteorological problems encountered. In addition to causing extra movement and set up of the sampling equipment, changes in wind direction also ruined upwind samples for some sampling periods in progress. Finally, several sampling days were lost due to rain.

SECTION 9

RESULTS FOR SOURCE TESTED BY BALLOON SAMPLING

SUMMARY OF TESTS PERFORMED

Blasting was the only source tested by the ballloon sampling method. Overburden and coal blasts were both sampled with the same procedure, but the data were kept separate during the data analysis phase so that the option of developing separate emission factors was available. A total of 18 successful tests were completed--14 for coal blasts and 4 for overburden blasts. Three more blasts were sampled, but the balloon was hit and broken in one and the plumes missed the sampler arrays in two others; no attempt was made to calculate emission rates for these three tests.

The overburden was not blasted at the mine in North Dakota (second mine), so overburden blast tests were confined to the first and third mines. The resulting sample size of four is not large enough for development of a statistically sound emission factor.

The sampling array consisted of balloon-supported samplers at five heights plus five pairs of ground-based hi-vols and dichots to establish the horizontal extent of the plume. No measure of deposition rate was made with this configuration because all samplers were at the same distance from the source.

Samplers at Mine 2 were located in the pit for coal blasts, but samplers at Mines 1 and 3 were located on the highwall above the pit. Therefore, some (prior) deposition is included in the emission rate measured at the latter mines. These are the only emission rates in the study that are not representative of emissions directly from the source.

Test conditions for the blasting tests are summarized in Table 9-1. An extremely wide range of blast sizes was sampled--from 6 to 750 holes and from 100 to 9600 m^2. The variation in moisture contents was also quite wide. The only potential correction factor with a limited range during testing was the depth of the holes. All the holes for coal blasts were about 20 ft deep. Overburden holes had a range of 25 to 135 ft, but there are not enough data points to develop a correction factor.

TABLE 9-1. TEST CONDITIONS FOR BLASTING

Test	Sampling conditions				Source characteristics				Soil properties	Meteorological conditions		
	Date	Start time	Duration, minutes	Samplers in or out of pit	No. of holes	Area, m^2	Tons of explosive	Depth of holes, ft	Moisture, %	Temp, °F	Wind speed, m/s	Stab class
Mine 1												
Coal 1	8/10/79	15:00	5	out	33	1100	1.0	22	22	82	1.1	A
2	8/10/79	15:30	3	out	6	100	0.2	22	22	82	1.0	A
3	8/14/79	12:00	7	out	42	1600	1.3	20	22	62	1.4	B
~~Ovb~~ 1	8/14/79	14:30	16	out	33	3400	12.0	70	7.2	66	5.1	D
Overburden 2	8/20/79	14:45	8	out	20	2200	10.0	60	7.2	76	2.0	A
Mine 2												
Coal 1	10/25/79	11:28	6	in	195	1100		20	38	45	2.6	C
2	10/26/79	11:00	8	in	210	1100		20	38	43	1.6	C
3	10/29/79	9:33	3	in	180	1000		20	38	43	1.8	C
4	10/29/79	12:07	6	in	150	800		20	38	43	1.0	B
5	10/29/79	14:30	7	in	110	1100		20	38	38	3.2	D
6	10/30/79	14:35	6	in	96	600		20	38	47	5.4	D
Mine 3												
Coal 2	7/28/80	14:20	13	out	250	4100		20	11.1	99	1.7	B
3	7/29/80	14:10	21	out	750	6800		20	11.1	104	1.2	B
4	8/01/80	13:10	25	out	200	3400		20	11.1	90	2.0	A
5	8/04/80	14:15	7	out	150	2400		20	11.1	95	2.7	C
6	8/06/80	10:45	12	out	160	2700		20	11.1	82	1.3	B
~~Ovb~~ 1	8/06/80	14:35	10	out	50	9600		135	8.0	93	1.7	A
Overburden 2	8/12/80	15:05	10	out	60	5000		25	8.0	95	1.0	A

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RESULTS

TSP emission rates are shown in Table 9-2. The emission rates varied over a wide range, from 1.1 to 514 lb/blast. Blasting emssions at the first two mines were relativley low; those at the third mine were quite high. Some of the differences are expected to be explained by test conditions, which also varied over a correspondingly wide range. The values in Table 9-2 are as measured, and have not been adjusted for any potential correction factors.

The data subsets by mine were too small for statistics such as standard deviation to be meaningful. If the data are divided into subsets of coal and overburden blasts, the TSP emission rates are as follows:

Type blast	No. samples	Mean, lb	Std dev	Range
Coal	14	110.2	161.2	1.1-514
Overburden	4	106.2	110.9	35.2-270

The only sample that was more than two standard deviations away from the mean was the 514 lb value. However, this blast had more than three times as many holes as any other blast sampled, so it would not be considered an outlier.

Inhalable and fine particulate emission rates are presented in Table 9-3.. The IP emission rates ranged from 0.5 to 142.8 lb/blast and from 17 to 138 percent of TSP. The IP emission rates for blasts averaged 46 percent of the TSP rates, about the same ratio as the haul roads. Fine particulate averaged 5.0 percent of TSP, higher than for any other source. Coal blasts and overburden blasts did not have any obvious distinctions in their respective particle size distributions.

PROBLEMS ENCOUNTERED

Balloon sampling represented a substantial modification of the exposure profiling method and therefore a somewhat experimental technique. It was particularly difficult to apply blasting because technical limitations of the technique combined with the infrequency of blasting resulted in very few opportunities to perform the sampling.

This sampling method could not be used when ground level winds were greater than about 6 m/s because the balloon could not be controlled on its tether. At wind speed less than about 1 m/s, wind direction tended to vary and the sampling array could not be located with any confidence of being in the plume. Also, at low wind speeds, the plume from the blast frequently split or rose vertically from the blast site. Therefore, sampling was constrained to a fairly narrow range of wind speeds.

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TABLE 9-2. APPARENT EMISSION RATES FOR BLASTING
High-Volume (30 μm)

Test No.	Pound/ blast	Distance from source, m	Test No.	Pound/ blast	Distance from source, m
Mine 1			Mine 1		
Coal			Overburden		
1	32.5	96	1	40.4	100
2	2.7	96	2	79.4	100
3	51.7	37			
Mine 2					
Coal					
1	8.8	130			
2	1.1	213			
3	10.7	130			
4	1.6	160			
5	40.3	170			
6	11.8	180			
Mine 3			Mine 3		
Coal			Overburden		
2	401	90	1	35.2	110
3	514	160	2	270	200
4	148	128			
5	113	53			
6	206	82			

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TABLE 9-3. APPARENT EMISSION RATES FOR BLASTING
Dichotomous (15 μm, 2.5 μm)

Test No.	Pound/blast		Distance from source, m	Test No.	Pound/blast		Distance from source, m
	IP	FP			IP	FP	
Mine 1 Coal				Mine 1 Overburden			
1	44.9[a]	3.62	96	1	32.9	0.79	100
2	1.56	0.32	96	2	48.9	0.09	100
3	17.3	1.23	37				
Mine 2 Coal							
1	1.55	0.10	130				
2	0.62	0.06	213				
3	3.57	0.80	130				
4	0.45	0.10	160				
5	15.30	1.27	170				
6	1.99	0.01	180				
Mine 3 Coal				Mine 3 Overburden			
2	123.4	10.4	90	1	16.9	3.5	110
3	142.8	12.3	160	2	93.9	16.2	200
4	87.9	13.0	128				
5	35.3	2.1	53				
6	71.3	19.8	82				

[a] Dichotomous concentrations are greater than hi-vol, value represents 20.5 μm cut point for IP.

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For safety reasons, a source-sampler distance of 100 m or more was usually required. At this distance, the plume could disperse vertically above the top sampler inlet under unstable atmospheric conditions.

Even though sampling was done at very large mines, only one or two blasts per day were scheduled. This often created difficulties in obtaining the prescribed number of blasting tests at each mine.

Since blasting was not a continuous operation, there was no continuous plume to provide assistance in locating the samplers. For coal blasts in particular, the portion of the plume below the high wasll usually was channeled parallel to the pit but any portion rising above the high wall was subject to ambient winds and often separated from the plume in the pit.

Finally, representative soil samples could not be obtained for this source because of the abrupt change in the characteristics of the soil caused by the blast. The moisture contents reported in Table 9-1 were for samples of coal in place and overburden from drilling tests (both prior ot blasting).

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SECTION 10

RESULTS FOR SOURCES TESTED BY WIND TUNNEL METHOD

SUMMARY OF TESTS PERFORMED

As discussed previously, the wind tunnel method was used to test particulate emissions generated by wind erosion of coal storage piles and exposed ground areas. These sources were tested at three mine sites during the period October 1979 through August 1980.

A total of 37 successful wind tunnel tests were conducted at the three mines. Tests at Mine 1 took place in late autumn, with below normal temperatures and snowfall being encountered. Emissions tests were distributed by source and by mine as follows:

	Number of tests		
Source	Mine 1	Mine 2	Mine 3
Coal storage piles	4	7	16
Exposed ground areas	1	5	4

The decision of when to sample emissions from a given test surface was based on the first observation of visible emissions as the tunnel flow rate was incrased. At Mines 1 and 2, if visible emissions in the blower exhaust were not observed at a particular tunnel flow rate, no air sampling was performed, but a velocity profile was obtained. Then the tunnel flow rate was increased to the next level and the process repeated. When visible emissions were observed, emission sampling was performed and then repeated at the smae wind speed (but for a longer sampling time) to measure the decay in the erosion rate. At Mine 3, particle movement on the test surface was used as the indicator that the threshold velocity had been reached and that emission sampling should be performed. Five tests on coal piles and seven tests on exposed ground areas were conducted on surfaces where no erosion was visually observed, and in these cases no emissions sampling was performed.

Tale 10-1 lists the test site parameters for the wind tunnel tests conducted on coal pile surfaces. The ambient temperature and relative humidity measurements were obtained just above the coal surface external to the tunnel.

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TABLE 10-1. WIND EROSION TEST SITE PARAMETERS - COAL STORAGE PILES

Mine/Site[a]	Run	Date	Start time (hr:sec)	Sampling duration (min:sec)	Ambient meteorology Temp. (°C)	R.H. (%)
Mine 1/Site A	J-22	11/9/79	-	-	-2.8	-
Mine 1/Site B	J-23	11/9/79	-	-	-2.8	-
	J-24	11/9/79	1330:00	5:30	-1.1	79
	J-25	11/9/79	1413:00	30:00	-1.1	79
Mine 1/Site C	J-26	11/9/79	1606:30	1:00	-1.1	79
	J-27	11/9/79	1620:15	8:15	-1.1	79
Mine 2/Site A	K-30	10/31/79	-	-	3.3	75
Mine 2/Site E	K-38	11/3/79	-	-	-1.1	100
	K-39	11/3/79	1417:25	6:00	2.8	61
Mine 2/Site F	K-40	11/3/79	1550:05	6:49	4.4	60
	K-41	11/3/79	1635:25	30:00	2.8	65
Mine 2/Site G	K-42	11/4/79	1120:00	5:50	2.8	64
	K-43	11/4/79	1156:20	30:00	3.9	70
Mine 2/Site H	K-44	11/4/79	-	-	2.2	-
	K-45	11/4/79	1652:40	3:35	2.8	51
	K-46	11/4/79	1717:40	30:00	2.8	51
Mine 3/Site A	P-20	8/12/80	0848:00	30:00	24	39
	P-21	8/12/80	0946:00	10:00	29	26
	P-22	8/12/80	1014:00	40:00	29	26

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TABLE 10-1 (continued).

Mine/Site[a]	Run	Date	Start time (hr:sec)	Sampling duration (min:sec)	Ambient meteorology Temp. (°C)	Ambient meteorology R.H. (%)
	P-23	8/12/80	1114:00	10:00	33	21
	P-24	8/12/80	1222:00	40:00	33	21
	P-25	8/12/80	1538:00	10:00	37	12
	P-26	8/12/80	1617:00	10:00	37	12
Mine 3/Site B	P-27	8/12/80	1813:00	2:00	37	12
	P-28	8/13/80	1017:00	8:00	28	35
	P-29	8/13/80	1134:00	2:00	34	24
	P-30	8/13/80	1146:00	8:00	34	24
Mine 3/Site C	P-31	8/13/80	1546:00	2:00	34	19
	P-32	8/13/80	1601:00	8:00	34	19
	P-33	8/13/80	1649:00	2:00	34	19
	P-34	8/13/80	1704:00	8:00	34	19
	P-35	8/13/80	1738:00	26:00	34	19

[a] Mine 1/Site A - Base of pile.
Mine 1/Site B - Traveled area (dozer track) surrounding pile.
Mine 1/Site C - Traveled area (light duty vehicle track) surrounding pile.
Mine 2/Site A - Raw coal surge pile.
Mine 2/Site E - Raw coal surge pile.
Mine 2/Site F - Raw coal surge pile.
Mine 2/Site G - Raw coal surge pile.
Mine 2/Site H - Along dozer track on raw coal surge pile.
Mine 3/Site A - Approximately 1 kilometer east of power plant on crusted vehicle track.
Mine 3/Site B - Twenty-five meters south of Site A on furrow in coal pile.
Mine 3/Site C - Seventy-five meters west of Site B on uncrusted haul truck track.

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Table 10-2 gives the tunnel test conditions for the wind erosion emission tests on coal surfaces. The equivalent speed at 10 m was determined by extrapolation of the logarithmic velocity profile measured in the wind tunnel test section above the eroding surface. The first friction velocity, which is a measure of the wind shear at the eroding surface, was determined from the velocity profile.

Table 10-3 gives the erosion-related properties of the coal surfaces from which wind-generated emissions were measured. The silt and moisture values were determined from representative undisturbed sections of the erodible surface ("before" erosion) and from the actual test surface after erosion; therefore, only one "before" condition and one "after" condition existed for each test site. The roughness height was determined from the velocity profile measured above the test surface at a tunnel wind speed just below the threshold value.

Table 10-3 lists the test site parameters for the wind tunnel tests conducted on exposed ground areas. The surfaces tested included topsoil, subsoil (with and without snow cover), overburden and scoria. For Runs J-28, K-31 through K-34, K-47 and K-48, no air sampling was performed, but velocity profiles were obtained.

Table 10-5 gives the tunnel test conditions for the wind erosion emission tests on exposed ground areas. Table 10-6 gives the erosion-related properties of the exposed ground surfaces from which wind-generated emissions were measured.

RESULTS

Table 10-7 and 10-8 present the wind erosion emission rates measured for coal pile surfaces and exposed ground areas, respectively. Emission rates are given for suspended particulate matter (particles smaller than 30 µm in aerodynamic diameter) and inhalable particulate matter (particles smaller than 15 µm in aerodynamic diameter).

For certain emission sampling runs, emission rates could not be calculated. No particle size data were available for run J-30. For exposed ground area runs P-37 and P-41, measured emissions consisted entirely of particles larger than 11.6 µm aerodynamic diameter (the cyclone cut point).

The means, standard deviations, and ranges of SP emission rates for each source category are shown below:

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TABLE 10-2. WIND TUNNEL TEST CONDITIONS - COAL STORAGE PILES

Run	Wind speed at tunnel centerline (m/s)	Wind speed at tunnel centerline (mph)	Friction velocity (m/s)	Friction velocity (mph)	Equivalent speed at 10 m (m/s)	Equivalent speed at 10 m (mph)
J-24	14.3	32.1	0.97	2.17	25.0	56.0
J-25	14.2	31.8	0.96	2.15	25.0	56.0
J-26	11.7	26.2	0.63	1.41	18.8	42.0
J-27	15.6	35.0	0.94	2.10	25.9	58.0
K-39	16.7	37.3	1.46	3.27	32.2	72.0
K-40	15.0	33.5	1.46	3.27	29.1	65.0
K-41	14.8	33.2	1.44	3.22	29.1	65.0
K-42	16.9	37.9	1.73	3.87	33.5	75.0
K-43	16.9	37.9	1.73	3.87	33.5	75.0
K-45	13.6	30.4	1.32	2.95	27.3	61.0
K-46	13.6	30.4	1.32	2.95	27.3	61.0
P-20	11.6	25.9	0.44	0.984	16.8	37.5
P-21	13.1	29.2	0.60	1.34	19.2	43.0
P-22	13.1	29.2	0.60	1.34	19.2	43.0
P-23	14.2	31.8	0.64	1.43	21.9	49.0
P-24	14.8	33.2	0.61	1.36	20.3	45.5
P-25	16.0	35.8	0.66	1.48	22.4	50.0
P-26	16.2	36.3	0.71	1.59	23.7	53.0
P-27	16.0	35.7	1.00	2.24	26.4	59.0
P-28	15.8	35.4	1.20	2.68	30.6	68.5

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TABLE 10-2 (continued).

Run	Wind speed at tunnel centerline		Friction velocity		Equivalent speed at 10 m	
	(m/s)	(mph)	(m/s)	(mph)	(m/s)	(mph)
P-29	17.3	38.6	1.31	2.93	>31.3	>70.0
P-30	16.9	37.7	1.08	2.42	26.4	59.0
P-31	11.8	26.3	0.91	2.04	21.5	48.0
P-32	12.0	26.8	0.95	2.12	24.6	55.0
P-33	14.5	32.4	1.15	2.57	26.6	59.5
P-34	14.4	32.2	1.25	2.80	31.3	70.0
P-35	14.5	32.4	1.25	2.80	>31.3	>70.0

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TABLE 10-3. WIND EROSION SURFACE CONDITIONS - COAL STORAGE PILES

Run	Silt		Moisture		Roughness Height (cm)	Threshold speed at tunnel centerline	
	Before (%)	After (%)	Before (%)	After (%)		(m/s)	(mph)
J-24	16.4	-	2.5	-	0.04	9.52	21.3
J-25	16.4	6.8	2.5	3.3	0.04	9.52[a]	21.3[a]
J-26	16.4	-	2.5	-	0.008	9.52[a]	21.3[a]
J-27	16.4	-	2.5	-	0.02	9.52[a]	21.3[a]
K-39	5.1	4.2	20.2	19.9	0.16	14.1	31.6
K-40	5.1	-	20.2	-	0.25	14.1	31.6
K-41	5.1	6.8	20.2	10.5	0.25	14.1	31.6
K-42	3.4	-	6.8	-	0.30	14.1	31.6
K-43	3.4	2.3	6.8	6.4	0.30	14.1	31.6
K-45	11.6	-	2.8	-	0.25	11.1	24.8
K-46	11.6	10.0	2.8	2.1	0.25	11.1	24.8
P-20	3.8	4.1	4.6	3.4	0.0005	8.76	19.6
P-21	3.8	4.1	4.6	3.4	0.0024	8.76	19.6
P-22	3.8	4.1	4.6	3.4	0.0024	8.76	19.6
P-23	3.8	4.1	4.6	3.4	0.0022	8.76	19.6
P-24	3.8	4.1	4.6	3.4	0.0009	8.76	19.6
P-25	3.8	4.1	4.6	3.4	0.0009	8.76	19.6
P-26	3.8	4.1	4.6	3.4	0.0017	8.76	19.6
P-27	4.0	3.8	7.8	5.1	0.025	14.6	32.6

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TABLE 10-3 (continued).

Run	Silt		Moisture		Roughness Height (cm)	Threshold speed at tunnel centerline	
	Before (%)	After (%)	Before (%)	After (%)		(m/s)	(mph)
P-28	4.0	3.8	7.8	5.1	0.078	14.6	32.6
P-29	4.0	3.8	7.8	5.1	0.078	14.6	32.6
P-30	4.0	3.8	7.8	5.1	0.030	14.6	32.6
P-31	4.4	-	3.4	-	0.085	8.32	18.6
P-32	4.4	-	3.4	-	0.10	8.32	18.6
P-33	4.4	-	3.4	-	0.10	8.32	18.6
P-34	4.4	-	3.4	-	0.15	8.32	18.6
P-35	4.4	-	3.4	-	0.15	8.32	18.6

[a] Assumed the same as J-24.

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TABLE 10-4. WIND EROSION TEST SITE PARAMETERS - EXPOSED GROUND AREAS

Mine/Site[a]	Run	Date	Start time (hr:sec)	Sampling duration (min:sec)	Ambient meteorology	
					Temp. (°C)	R.H. (%)
Mine 1/Site D	J-28	11/10/79	-	-	0.6	-
	J-29	11/10/79	1141:00	30:00	0.6	91
	J-30	11/10/79	1342:30	30:10	2.8	87
Mine 2/Site B	K-31	11/1/79	-	-	2.2	60
	K-32	11/1/79	-	-	2.2	60
	K-33	11/1/79	-	-	2.2	60
Mine 2/Site C	K-34	11/2/79	-	-	-1.7	80
	K-35	11/2/79	1454:00	3:21	-1.7	80
	K-36	11/2/79	1536:00	30:36	-1.7	80
Mine 2/Site D	K-37	11/2/79	1704:17	11:43	-1.7	80
Mine 2/Site I	K-47	11/5/79	-	-	-1.1	-
Mine 2/Site J	K-48	11/5/79	-	-	-1.1	-
	K-49	11/5/79	1515:00	5:00	0.6	63
Mine 2/Site J	K-50	11/5/79	1555:30	28:00	0.0	75
Mine 3/Site D	P-36	8/14/80	1012:00	2:00	-	-
	P-37	8/14/80	1026:00	4:00	-	-
	P-38	8/14/80	1042:00	4:00	-	-
Mine 3/Site E	P-39	8/14/80	1212:00	4:00	-	-
Mine 3/Site E	P-40	8/14/80	1225.00	4.00	-	-
	P-41	8/14/80	1240.00	4.00	-	-

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Footnotes for Table 10-4.

a Mine 1/Site D - Subsoil covered with one-half inch of snow, which melted prior to Run J-30.
Mine 2/Site B - Exposed soil near pit.
Mine 2/Site C - Dragline access road recently cut down; road surface represented disturbed overburden.
Mine 2/Site D - Adjacent to Site C and in same material.
Mine 2/Site I - Small bank made of overburden and left by grader on side of unpaved road.
Mine 2/Site J - Scoria haul road.
Mine 3/Site D - Exposed topsoil. Two hundred meters south of pit.
Mine 3/Site E - Five meters west of Site D.

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TABLE 10-5. WIND TUNNEL TEST CONDITIONS - EXPOSED GROUND AREAS

Run	Wind speed at tunnel centerline (m/s)	Wind speed at tunnel centerline (mph)	Friction velocity (m/s)	Friction velocity (mph)	Equivalent speed at 10 m (m/s)	Equivalent speed at 10 m (mph)
J-29	18.1	40.5	1.96	4.38	38.0	85.0
J-30	16.6	37.1	1.62	3.62	32.6	73.0
K-35	15.1	33.7	1.54	3.44	30.9	69.0
K-36	14.8	33.1	1.51	3.38	30.0	67.0
K-37	15.1	33.7	1.54	3.44	30.9	69.0
K-49	15.8	35.4	1.56	3.49	30.4	68.0
K-50	15.8	35.4	1.56	3.49	30.4	68.0
P-36	10.3	19.6	0.87	1.95	15.7	35.0
P-37	10.3	19.6	0.87	1.95	15.7	35.0
P-38	10.3	19.6	0.87	1.95	15.7	35.0
P-39	6.3	14.0	0.33	0.738	10.3	23.0
P-40	8.1	18.0	0.44	0.984	13.0	29.0
P-41	10.7	23.9	1.00	2.24	20.1	45.0

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TABLE 10-6. WIND EROSION SURFACE CONDITIONS - EXPOSED GROUND AREAS

Run	Silt Before (%)	Silt After (%)	Moisture Before (%)	Moisture After (%)	Roughness Height (cm)	Threshold speed at tunnel centerline (m/s)	Threshold speed at tunnel centerline (mph)
J-29	-	-	-	-	0.38	>18.3	>41
J-30	-	-	-	-	0.25	>18.3	>41
K-35	21.1	18.8	6.4	5.6	0.30	10.5	23.4
K-36	21.1	18.8	6.4	5.6	0.30	10.5	23.4
K-37	21.1	22.7	6.4	5.6	0.30	10.5	23.4
K-49	18.8	-	4.1	-	0.26	13.5	30.1
K-50	18.8	15.1	4.1	2.7	0.26	13.5	30.1
P-36	5.1	-	0.8	-	0.13	4.65	10.4
P-37	5.1	-	0.8	-	0.13	4.65	10.4
P-38	5.1	-	0.8	-	0.13	4.65	10.4
P-39	5.1	-	-	-	0.0075	5.14	11.5
P-40	5.1	-	-	-	0.01	5.14	11.5
P-41	5.1	-	-	-	0.21	5.14	11.5

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TABLE 10-7. WIND EROSION TEST RESULTS - COAL STORAGE PILES

Run	Emission rate			
	Suspended particulate		Inhalable particulate	
	(g/m²-s)	(lb/acre-s)	(g/m²-s)	(lb/acre-s)
J-24	0.00340	0.0303	0.00226	0.0202
J-25	0.00520	0.0464	0.00344	0.0307
J-26	0.254	2.27	0.157	1.40
J-27	0.0748	0.668	0.0472	0.421
K-39	0.170	1.52	0.119	1.06
K-40	0.111	0.991	0.0722	0.644
K-41	0.00454	0.0405	0.00296	0.0264
K-42	0[illegible]961	0.831	0.0626	0.559
K-43	0.00436	0.0389	0.00279	0.0249
K-45	0.0598	0.534	0.0436	0.389
K-46	0.00741	0.0661	0.00548	0.0489
P-20	0.0127	0.113	0.00811	0.0724
P-21	0.00966	0.0862	0.00414	0.0369
P-22	0.00108	0.00964	0.000597	0.00533
P-23	0.00232	0.0207	0.00139	0.0124
P-24	0.00176	0.0157	0.00107	0.00955
P-25	0.00392	0.0350	0.00231	0.0206
P-26	0.00948	0.0846	0.00533	0.0476
P-27	0.0386	0.344	0.0202	0.180
P-28	0.00578	0.0516	0.00343	0.0306

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TABLE 10-7 (continued).

Run	Emission rate			
	Suspended particulate		Inhalable particulate	
	(g/m²-s)	(lb/acre-s)	(g/m²-s)	(lb/acre-s)
P-29	0.0161	0.144	0.0112	0.100
P-30	0.00168	0.0150	0.000970	0.00866
P-31	0.0191	0.170	0.0101	0.0901
P-32	0.00231	0.0206	0.000943	0.00842
P-33	0.0274	0.245	0.0157	0.140
P-34	0.00605	0.0540	0.00303	0.0270
P-35	0.00278	0.0248	0.00185	0.0165

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TABLE 10-8. WIND EROSION TEST RESULTS - EXPOSED GROUND AREAS

Run	Emission rate			
	Suspended particulate		Inhalable particulate	
	(g/m^2-s)	(lb/acre-s)	(g/m^2-s)	(lb/acre-s)
J-29	0.00160	0.0143	0.00108	0.00964
J-30[a]	-	-	-	-
K-35	0.0368	0.329	0.0245	0.219
K-36	0.00120	0.0107	0.000822	0.00734
K-37	0.00693	0.0618	0.00458	0.0409
K-49	0.0337	0.301	0.0222	0.198
K-50	0.000782	0.00698	0.000652	0.00582
P-36	0.0161	0.144	0.0101	0.0901
P-37	0.0305	0.272	0.0190	0.170
P-38	0.0602	0.537	0.0377	0.336
P-39[b]	-	-	-	-
P-40	0.116	0.104	0.00755	0.0674
P-41[b]	-	-	-	-

[a] No particle size data available.

[b] Emissions consisted entirely of particles larger than 11.6 μm aerodynamic diameter.

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Source	**No. tests**	**SP emission rate (lbs/acre-s)** **Mean**	**Std. dev.**	**Range**
Coal piles				
On pile, uncrusted	**16**	**0.318**	**0.439**	**0.0150-1.52**
On pile, crusted	**7**	**0.0521**	**0.0415**	**0.00964-0.113**
Surrounding pile	**4**	**0.754**	**1.054**	**0.0303-2.27**
Exposed ground areas				
Soil, dry	**4**	**0.264**	**0.195**	**0.104-0.537**
Soil, wet	**1**	**0.0143**		**0.0143**
Overburden	**5**	**0.142**	**0.160**	**0.00698-0.329**

It can be seen that natural surface crusts on coal piles are effective in mitigating wind-generated dust emissions. In addition, emissions from areas surrounding piles appear to exceed emissions from uncrusted pile surfaces but are highly variable.

With reference to the rates measured for exposred ground areas, emissions from more finely textured soil exceed emissions from overburden. As expected, the presence of substantial moisture in the soil is effective in reducing emissions.

Examinations of the conditions under which tests were conducted indicates (1) an increase in emission rate with wind speed and (2) a decrease in emission rate with time after onset of erosion. This must be considered in comparing emission rates for different source conditions.

PROBLEMS ENCOUNTERED

The only significant problem in this phase of the study was the unforeseen resistance of selected test surfaces to wind erosion. Threshold velocities were unexpectedly high and occasionally above the maximum tunnel wind speed. This occurred primarily because of the presence of natural surface crusts which protected against erosion. As a result, the testing of many surfaces was limited to determination of surface roughness heights.

Although testing of emissions was intended to be restricted only to dry surfaces, the occurrence of snowfall at Mine 1 provided an interesting test condition for the effect of surface moisture. This helps to better quantify the seasonal variation in wind-generated emissions.

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SECTION 11

RESULTS FOR SOURCE TESTED BY QUASI-STACK SAMPLING

SUMMARY OF TESTS PERFORMED

Overburden drilling was the only source tested by the quasi-stack method. A total of 30 tests were conducted--11 at the first mine, 12 at the winter visit to the first mine, and 7 at the third mine. No drilling samples were taken at the second mine because the overburden was not shot, and hence not drilled, at that mine. No testing was done for coal drilling because it was not judged to be a significant source.

Sampling was done on the downwind side of the drill platform; the enclosure was to contain all the plume coming from beneath the platform. Four isokinetic sampling heads were located across the far side of the enclosure. Each collected particulate matter in a settling chamber and on a filter. Because of the proximity of the sampling inlets to the source (2 to 3 m), the assumption was made that the filter catch was the suspended material and the settling chamber was the settleable material.

Test conditions for the drill tests are summarized in Table 11-1. Testing took place over a wide range of drilling depths (30 to 110 fit) and soil silt contents (5.2 to 26.8 percent), so these can be evaluated as correction factors. However, there was very little variation in the moisture contents of the samples. No determination was made whether this was due to the undisturbed overburden material having a fairly narrow range of moisture contents or whether it was coincidence that all moisture contents were in the range of 7 to 9 percent. In either case, moisture content is not a candidate for a correction factor because of the narrow range of observed values.

The wind speeds reported in Table 11-1 are not ambient speeds; they are the average speeds measured by a hot-wire anemometer at the far end of the enclosure. In general, they were much lower than ambient because the wind was blocked by the drilling rig and platform. The speeds shown in the table are the averages for each sampling period of speeds and the sampling heads were set at to sample isokinetically. The four heads were adjusted individually based on wind speed measurements taken at that point in the enclosure. Wind speed profiles were observed to be fairly uniform across the enclosure, especially in comparison with traverses across a stack.

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TABLE 11-1. TEST CONDITIONS FOR DRILLS

Test	Date	Start time	Sampling duration, minutes	Source characteristics		Soil properties		Meteorological conditions	
				Depth, feet	Drill dia. in.	Silt, %	Moisture, %	Temp, °F	Wind speed, m/s
Mine 1									
1	7/31/79	11:00	12	45	12.5	26.8	7.7	85	1.5
2	7/31/79	12:30	17	45	12.5	26.8	7.7	90	1.1
3	7/31/79	12:58	10	45	12.5	26.8	7.7	91	1.5
4	7/31/79	13:15	7	45	12.5	26.8	7.7	91	1.5
5	7/31/79	13:40	8	45	12.5	26.8	7.7	93	1.0
6	8/16/79	9:00	29	75	12.5	23.3	7.2	67	0.5
7	8/16/79	9:45	35	75	12.5	23.3	7.2	73	0.5
8	8/16/79	10:15	34	75	12.5	23.3	7.2	74	1.3
9	8/16/79	11:00	37	75	12.5	23.3	7.2	75	1.5
10	8/16/79	12:00	34	75	12.5	23.3	7.2	73	1.8
11	8/16/79	13:30	39	75	12.5	23.3	7.2	70	1.5
Mine 1W									
1	12/05/79	10:40	41	90	12.2	5.2	7.4	59	1.4
2	12/05/79	11:21	37	50	12.2	5.2	7.4	63	1.4
3	12/05/79	13:02	58	90	12.2	5.2	7.4	64	2.8
4	12/06/79	9:48	26	50	12.2	5.2	7.4	45	1.0
5	12/06/79	10:35	46	90	12.2	5.2	7.4	51	1.6
6	12/06/79	11:25	33	90	12.2	5.2	7.4	51	1.3
7	12/07/79	7:30	47	100	12.2	9.3	7.4	33	0.9
8	12/07/79	8:35	49	100	12.2	9.3	7.4	33	0.8
9	12/07/79	9:40	68	100	12.2	9.3	7.4	33	0.7
10	12/07/79	11:00	25	50	12.2	9.3	7.4	33	0.4
11	12/07/79	12:45	18	50	12.2	9.3	7.4	34	0.5
12	12/07/79	13:30	60	100	12.2	9.3	7.4	34	0.4
Mine 3									
1	7/23/80	12:37	39	110	12.0	6.9	9.0	88	1.5
2	7/23/80	13:25	72	110	12.0	6.9	9.0	89	2.5
3	7/24/80	9:57	6	30	9.9	11.1	6.9	78	1.3
4	7/24/80	11:38	26	60	9.9	11.1	6.9	81	1.3
5	7/24/80	12:10	8	30	9.9	11.1	6.9	89	1.5
6	7/24/80	12:39	7	30	9.9	11.1	6.9	90	1.0
7	7/24/80	13:02	9	30	9.9	11.1	6.9	90	1.0

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RESULTS

The results of the drill tests are shown in Table 11-2. The values labeled "filter" are suspended particulate, comparable to TSP emission rates by other sampling methods. No smaller size fractions than suspended particulate were obtained for this source. The filter catch averaged only 14.2 percent of the total catch (filter plus settling chamber), indicating that most of the material emitted from the drill holes was of large particle size, and therefore readily settleable. This appears to be a reasonable finding, since a large portion of the emissions were produced by an air blast as the drill first entered the ground.

The total emissions per test had much wider variation than the suspended portion (filter catch). However, the total emission values were not used for development of any emission factor, so this variation was of little consequence.

The units for the TSP emission rates are lb/hole. The overall range of emission rates was wide--0.04 to 7.29 lb/hole--but ranges for subsets from the individual mine visits were considerably narrower. The statistics for the three subsets by mine visit are:

Mine	No. samples	Mean, lb/hole	Std dev	Range
1	11	0.84	0.84	0.04-2.43
1W	12	1.98	1.21	0.06-3.38
3	7	4.73	1.95	1.79-7.29

None of the samples were outliers (more than two standard deviations away) from the mean value of their subsets. The mean TSP emission rate for the 30 samples was 2.20 lb/hole and the standard deviation was 1.97. Only one value, 7.29, was more than two standard deviations away from this mean. This distribution is prior to inclusion of correction factors, which are expected to explain part of the observed variation in emission rates.

PROBLEMS ENCOUNTERED

The quasi-stack sampling method had not been used previously on any open fugitive dust sources similar to those at surface mines. However, the method worked well for sampling drilling emissions and only a few problems were encountered. The most important problem was that part of the plume sometimes drifted outside the enclosure when a change in wind direction occurred. No method could be found to account for this in estimating source strength, so it was ignored in the calculations. The effect of emissions escaping the enclosure was to underestimate actual emission rate, possibly by as much as 20 percent (based on the maximum volume of visible plume outside the enclosure).

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TABLE 11-2. APPARENT EMISSION RATES FOR DRILLING
(lb/hole)

Mine 1	Filter	Total	Mine 1W	Filter	Total	Mine 3	Filter	Total
1	1.18	6.75	1	0.76	5.80	1	3.06	21.07
2	0.20	0.75	2	3.38	43.46	2	7.29	35.23
3	0.24	0.81	3	2.57	144.93	3	4.65	12.72
4	0.04	0.28	4	1.95	23.52	4	6.48	22.18
5	0.17	0.47	5	2.54	111.72	5	4.04	15.92
6	0.11	1.92	6	2.91	44.34	6	1.79	9.96
7	0.33	7.61	7	3.35	68.50	7	5.84	26.47
8	1.56	24.31	8	3.05	40.71			
9	1.98	50.31	9	2.23	34.86			
10	2.43	41.01	10	0.53	2.09			
11	0.95	12.69	11	0.06	1.04			
			12	0.45	3.88			

Another problem with the sampling method was that no particle size data were obtained. Collection of millipore samples for microscopic analysis was originally planned, but the particle size data obtained by microscopy in the comparability study did nt agree well with that from aerodynamic sizing devices.

A third problem was securing representative soil samples. As the drilling progressed, soil brought to the surface sometimes changed in appearance as different soil strata were encountered. Usually, a composite of the different soils was collected to be submitted as the soil sample. However, the soil type discharged for the longest period of time or multiple samples could have been taken. Also, there was no assurance that soil sppearance was a good indicator of changes in its moisture or silt content.

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SECTION 12

EVALUATION OF RESULTS

EMISSION RATES

A total of 265 tests were conducted during the four sampling periods at three mines. The tests for each source were distributed fairly uniformly across the three mines, as previously shown in Table 3-8, despite difficulties in obtaining tests of particular sources at each mine. The total number of tests for each source was based on sample variance of data from the first two mines; required sample sizes were calculated by the two-stage method described in Section 5.

As in any fugitive dust sampling effort, several problems were encountered during the study:

Large average differences in concentrations were obtained for collocated samples, indicating imprecision of the sampling techniques.

Inability to control the mining operations led to some tests in which data had to be approximated or some operation cycles excluded.

Handling problems with the dichotomous filters may have contributed to an underestimate of emission rates in some cases.

Representative soil samples could not be obtained for some tests because of accessibility problems, etc., so moisture and silt values from prior or later tests had to be substituted.

However, the errors introduced by these problems appeared to be small in relation to the natural variance in emission rates of the sources as a result of meteorology, mining equipment, operation, etc. In other words, selection of time and place for sampling probably had far more impact on the resulting emission rates than problems associated with measurement of the rates.

The selection of mines may also have influenced final emission factors. Emission rates measured at Mines 1 and 2 were generally in the same range. However, the emission rates measured at Mine 3 were in general outside the range of values from Mines 1 and 2. Correction factors were used to explain the range in values so that the average rates employed in determining the final emission factors would not be biased by the high values from Mine 3.

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For all three mines, the relative standard deviations, a measure of variation in the sample data, ranged from 0.7 to 1.5 for different sources. Emission rates for most sources varied over two orders of magnitude in sample size of 12 to 39. Similar variation was observed in some of the independent variables thought to have an effect on emission rates.

The remainder of this section is devoted primarily to three aspects of the test data--particle size distribution, deposition, and effectiveness of control measures. The evaluation of the independent variables and their effect on emission rates in discussed in Section 13.

PARTICLE SIZE DISTRIBUTIONS

Considerable effort was expended in the comparability study evaluating three particle sizing methods--cascade impactors, dichotomous samplers, and microscopy. The comparison of methods, presented in Section 6, showed that the cascade impactors and dichotomous samplers gave approximately the same particle size distributions. In contrast, the microscopy data varied widely. It was concluded that microscopy is a useful tool for semiquantitative estimates of various particle types but is inadequate for primary particle sizing of fugitive dust emissions.

Cascade Impactor Data

As mentioned in Section 3, greased substrates were used in cascade impactors operated at the third mine to minimize particle bounce-through. The effectiveness of this preventive measure was checked by comparing the relative amounts of particulate catch on the back-up filter and on teh impactor substrates of cyclone/impactor sample with and without greased substrates.

In Table 12-1, cyclone/impactor samples of uncontrolled emissions from each source category at Mines 1 and 2 (where ungreased substrates were used) are compared with samples of the same sources from Mine 3. Sampling heights for the impactor varied slightly by mine, which introduces another variable into the comparison. It is evident from Table 12-1 that greasing produces little change in the proportion of material caught on the back-up filter. Only in the case of haul trucks does a positive effect of greasing appear. On the other hand, the single scraper emission sample collected at the third mine shows a larger portion of particulate on the back-up filter. Although comparisons of this type should ideally be based on collocated samplers, no readily identifiable pattern for the effect of greasing emerges from this comparison.

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TABLE 12-1. COMPARISON OF SAMPLE CATCHES ON GREASED AND UNGREASED IMPACTOR SUBSTRATES

Source	Mine	Sampling height, m	No. of runs	Mean ratio of back-up filter catch to substrate catch
Scrapers	1	2.0	3	0.245
	2	2.5	4	0.254
	3	1.5	1[a]	0.419
Graders	2	2.5	5	0.367
	3	1.5	2	0.361
Light- and medium-duty vehicles	1	2.0	3	0.315
	2	2.5	4	0.350
	3	1.5	3	0.380
Haul trucks	1	2.0	4	0.339
	2	2.5	5	0.314
	3	1.5	3	0.245

[a] It may be significant that this run had the lowest emission rate of the scraper tests.

Note: Samples at Mines 1 and 2 were collected on ungreased substrates; samples at Mine 3 were collected on greased substrates.

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Dichotomous Sampler Data

At the outset of the study, it was hypothesized that, as the larger particles fell out of the plume downwind of a mining source, the fraction of the remaining suspended particulate less than 15 μm and less than 2.5 μm would increase. Further, it was expected that only a small percentage of the particulate generated by a source would be in the less than 2.5 μm range. The test data obtained from the dichotomous samples supported both of these hypotheses.

While the data produced the expected results, there were several inherent limitations in the sampling technique that were discovered during the study. These were: the small sample weights collected for the fine particle samples; the low ratio of net weight to tare weight of the filter media; and the variable particle size cut point of the inlet.

The small sample weights on the fine filters were attributed to two causes: the low volume of air collected and the small amount of particulate less than 2.5 μm present in the plumes. Since the flow rate of the sampler was so low, 1.0 m^3/h, only a small amount of mass was collected when the concentrations were low. The net weight of the particulate collected on the fine quality assurance in weighing. These net weights were only a small fraction of the tare weight of the filter. Consequently, the potential weighing error was much higher for the dichotomous filters than for hi-vol filters, which collect a much greater mass. However, the number of filters checked that exceeded the 100 μg tolerance in weighing was almost the same for dichotomous filters (5 of 281) as it was for hi-vol filters (7 of 774), which had an allowable tolerance of 3.0 mg.

An associated problem was the filter media itself. The dust particles did not adhere well to the Teflon surface. Rather, the particulate remained on the surface of the filter where it was easily dislodged. Extensive quality assurance procedures were implemented for the handling of the filters to minimize particle losses. These procedures were discussed in Section 4.

The light loadings on the fine filter stages presented additional problems during the calculation procedures. A negligible mass on the fine filters resulted in a negligible concentration. For the upwind-downwind sampling, 25 percent of all the fine filters had calculated concentrations of zero. There was little variation in this number between sources. The individual percentages ranged from 18 to 30 percent. The problem was further complicated when upwind concentrations were substracted from downwind concentrations. An additional 10 to 20 percent of the fine concentrations became negligible after accounting for upwind concentrations.

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These negligible values, by themselves, were not a problem. The data simply indicated that there were no measureable emissions in the less than 2.5 µm size range. However, the particle size cut point of the inlet is dependent on wind speed (Wedding 1980). Consequently, measured coarse concentrations had to be corrected to a 15 µm cut point. This adjustment was based on an assumed lognormal distribution of particles in the 2.5 to 30 µm range. In order to determine the 15 µm value, a concentration different from zero was needed for the less than 2.5 µm size. As discussed in Section 5, the concentration resulting from the minimum detectable mass was substituted for any negligible downwind concentrations.

This substitution had the effect of artificially raising the fine particulate concentration for each source. This change resulted in an increase in average FP concentrations of about 10 percent.

Even though there were problems with the dichotomous sampler data, this sampler was chosen for generating the final particle size data for several reasons:

1. During the study design, the dichotomous sampler was the EPA method of choice for selective particle size sampling. As such, it is considered state-of-the-art for ambient particle size measurements.

2. The cascade impactor could not be conveniently used. Data from the comparability studies showed that comparison of dichotomous sampler and cascade impactor results was reasonable. However, no upwind impactor data were generated. Also, PEDCo did not use any impactors.

3 Both contractors used the same type of dichotomous sampler. As shown in Section 6, the dichotomous sampler produced internally consistent results. Therefore, it was expected that particle size data generated by both contractors would be consistent.

4. Based on the results of the comparability studies, the dichotomous sampler gave the most consistent results of the three method evaluated. Extensive project resources were expended to fine the most valid particle sizing method. Special quality assurance procedures were developed and implemented to control problems in the data. The precision of collocated dichotomous samplers and the number of filters that exceeded the quality assurance tolerance in weighing (5 out of 281) were about the same as that for hi-vols (7 out of 774).

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Particle Size Distribution Data

The average fraction of particles less than 15 µm and less than 2.5 µm are shown in Table 12-2. The data for each source are expressed as fractions of TSP for upwind-downwind tests and as fractions of SP (less than 30 µm diameter particles) for profiling and wind tunnel tests. These fractions were calculated from the raw test results presented in in Sections 6 through 11.

As shown in the table, IP fractions are reasonably consistent. They vary from 0.30 to 0.67. The FP/TSP ratios have a much wider variation, from 0.026 to 0.196. The 0.196 value for overburden dozers appears to be an anomaly. Excluding this value, the range is from 0.026 to 0.074. The high overburden dozer ratios are due to the assumption of minimum detectable concentrations on the fine filters combined with low TSP concentrations for most of these tests.

Also evident from the table is that the standard deviation values are generally higher for sources measured with the upwind/downwind technique as opposed to the profiler technique. This difference is inherent in the sampling configurations. Upwind/downwind data are generated from multiple downwind distances and are the average of several points. In contrast, profiler data are gathered at a single point 5 m from the source.

DEPOSITION

Data for quantifying deposition were generated in three ways:

1. For 48 profiling tests, deposition was measured by collocated dustfall buckets at 5, 20, and 50 m downwind of the source.
2. For 77 upwind-downwind sampling tests, deposition was determined by apparent source depletion with distance. Measurements were made at four downwind distances at a maximum distance of 200 m downwind of the source.
3. For 10 comparability tests, exposure profiling and upwind-downwind samplers were run on a common source so that simultaneous measurements by these methods could be compared. Downwind distances were 5, 20, and 50 m.

Dustfall

A consistent reduction in dustfall rates with distance from the source was found in 38 of 48 successful exposure profiling tests. The average difference between collocated dustfall buckets was 42.6 percent.

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TABLE 12-2. PARTICLE SIZE DISTRIBUTIONS BASED ON NET CONCENTRATIONS

Source	n	Average IP/TSP	Std. dev. of IP/TSP	Average FP/TSP	Std. dev. of FP/TSP
Blasting	18	0.44	0.28	0.051	0.039
Coal loading	24	0.30	0.15	0.030	0.035
Dozer, coal	12	0.49	0.24	0.031	0.033
Dozer, ~~ovb.~~ overburden	14	0.54	0.54	0.196	0.218
Dragline	19	0.32	0.22	0.032	0.040
Light- and medium-duty vehicles[a]	11	0.65	0.16	0.074	0.078
Scrapers[a]	14	0.49	0.07	0.026	0.021
Graders[a]	7	0.48	0.10	0.055	0.041
Haul trucks[a]	28	0.52	0.08	0.033	0.037
Coal storage piles[a]	27	0.61	0.08		
Exposed areas[a]	10	0.67	0.06		

[a] Expressed as ratios of SP (suspended particulate, <30 μm) rather than TSP.

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The dustfall rates for each test were converted to equivalent depletion factors (ratio between the apparent emission rate, Q_x, at a distance x downwind and the initial emission rate, Q_o) by a four step procedure:

1. Total dustfall from 5 m to 20 m and from 20 m to 50 m was calculated by multiplying the average dustfall rate over each distance times the distance. The resulting total dustfall values were in units of mg/m-min.

2. The initial emission rate for each test corresponding to the dustfall rates was total particualte (TP). The TP emission rate was converted from lb/VMT to mg/m-min, using the number of vehicle passes and the sampling duration of the test.

3. The total dustfall values for each distance were divided by the initial emission rate to determine the fraction of TP emissions deposited over that distance.

4. The depletion factor, or fraction of initial emissions remaining airborne, for TP to any distance (20 to 50 m in this case) was 1.0 minus the total fraction deposited by that distance.

The calculated depletion factors for each profiling test in which dustfall measurements were taken (excluding the comparability tests) are shown in Table 13-3. Deposition, measured as dustfall and expressed as a fraction of initial emissions, appeared to be very uniform from test to test and from source to source. This was evident from the low standard deviations compared to mean values.

The deposition rates by test were correlated with several potential variables such as wind speed and particle size distribution. These analyses did not reveal any significant relationships that could form the basis for an empirical deposition function.

Apparent Source Depletion

Consistent source depletion over the three or four downwind sampling distances was evident in only 13 of 77 upwind-downwind tests. The average depletion factors at all downwind distances were substantially greater than 1.0 (indicating plume enhancement rather than depletion).

The average TSP depletion factors for each source sampled by the upwind-downwind method are presented in Table 12-4. Every one of the sources except haul roads displayed an increase in apparent emission rates with distance.

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TABLE 12-3. DEPLETION FACTORS CALCULATED FROM DUSTFALL MEASUREMENTS

Source/ test No.	Depletion factor (Q_x/Q_0)		Source/ test No.	Depletion factor (Q_x/Q_0)	
	At 20 m	At 50 m		At 20 m	At 50 m
Haul trucks			Light-duty veh.		
J11	0.84	0.76	J13	0.95	0.92
K1	0.91	0.79	J18	0.97	0.97
K6	0.91	0.84	J19	0.96	0.91
K7	0.87	0.68	K2	0.96	0.91
K8	0.94	0.93	K3	0.97	0.93
K9	0.95	0.93	K4	0.92	0.81
K10	0.88	0.75	K5	0.92	0.80
K11	0.89	0.78	P11	0.92	0.87
K12	0.90	0.77	P12	0.89	0.84
K13	0.92	0.88	Average	0.940	0.887
K26	0.94	0.92	Std. dev.	0.028	0.060
L1	0.95	0.92			
L2, L3, L4	0.98	0.97	Scrapers		
P1	0.94	0.89	K15	0.92	0.86
P2*	0.82	0.50	K16	0.98	0.93
P4	0.99	0.98	K17	0.78	0.72
P5	0.98	0.96	K18	0.82	0.76
P6	0.93	0.80	K22	0.85	0.69
P7	0.98	0.96	K23	0.93	0.85
P8	0.99	0.99	L5, L6	0.99	0.98
P9	0.99	0.99	Average	0.896	0.827
Average	0.929	0.856	Std. dev.	0.081	0.109
Std. dev.	0.050	0.124			
			Graders		
			K19	0.88	0.73
			K20	0.92	0.75
			K21	0.84	0.62
			K24	0.78	0.51
			K25	0.84	0.65
			P16	0.80	0.66
			P17	0.95	0.90
			Average	0.859	0.689
			Std. dev.	0.062	0.122
			Avg. of 44 tests	0.914	0.831

* Test had 2 bad passes.

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The standard deviations of the depletion factors displayed two characteristics: relative standard deviations (RSD) consistently increased with distance from the source; and the RSD values were fairly high, indicating much variation in results from the individual tests.

Interestingly, the haul road tests had similar depletion rates to the comparability tests (which were conducted on haul roads and scrapers) when differences in wind speed were considered. This observation led to another comparison--between tests in which the source was sampled as a line source and those in which it was sampled as a point source. The 15 line source tests had average depletion fctors less than 1.0, but did not demonstrate continuing deposition with increasing distance. In contracts, the point source tests had average depletion factors of 1.36, 1.35, and 1.52 at three successive distances from the source. The IP data could not be effectively analyzed for source depletion because dichotomous samplers were placed at only the first two distances in all upwind-downwind tests after the comparability tests.

Comparability Study

A discussion of deposition data from the comparability studies is contained in Section 6. Data are summarized in Figure 6-7. Dustfall data were not meaningful because of data scatter. For exposure profiling, the 30 um depletion factors at 20 m and 50 m were found to be 108 percent (source enhancement) and 55 percent. Corresponding TSP data for upwind-downwind sampling was found to be 87 percent and 56 percent. The data for 50 m from both measurement techniques indicated considerably greater source depletion than was found in 44 exposure profiling tests with dustfall measurements (Table 12-3).

Comparison of Sources of Deposition Data

Data analyzed with respect to deposition were dustfall buckets from profiling tests; source depletion from upwind-downwind tests; and profiling data from the comparability study. These analyses did not reveal any significant relationships that could form the basis for an empirically derived deposition function. Because these analyses were nonproductive and the primary method of measuring deposition (apparent source depletion in upwind-downwind sampling) gave unstable results, a deposition function cannot be presented at this time. However, several conclusions can be drawn.

Based on experience gained from this study, it is recommended that future dustfall measurement be performed with the following considerations:

1. Dustfall measurements at various distances downwind of the source should be accompanied by a coincident upwind measurement that is subtracted as a background value. Dustfall data for a

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TABLE 12-4. DEPLETION FACTORS FOR UPWIND-DOWNWIND TESTS

Tests	Pt or line	No. tests	TSP depletion factor 20-40 m	TSP depletion factor 50-70 m	TSP depletion factor 80-100 m	Average stability class	Average wind speed, m/s
Coal loading	P	25	1.63	1.40	1.63	B-C	2.3
Dozer, ~~ovb.~~ overburden	P	11	1.04	1.20	1.28	B-C	3.3
	L	4	0.90	0.99	1.40	B-C	2.3
Dozer, coal	P	7	0.96	1.60	1.46	C	3.5
	L	5	1.19	1.22	1.33	C-D	4.7
Dragline	P	19	n.d.	1.32	1.61	C	3.6
Haul trucks	L	6	0.78	0.79	0.64	D	5.0
All uw.-dw. (except compar.)	P	62	1.36	1.35	1.52	C	3.5
	L	15	0.81	0.98	0.98	C	4.2

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test should be invalidated if the upwind sample is impacted by the source as a result of wind reversal.

2. The measurements should be done in duplicate to reduce error and so that the precision of the measurement can be assessed.

3. Measurements should be taken at distances greater than 50 m to quantify the continuing fallout of particles. However, at greater distances, collection of a detectable mass of dustfall during a short sampling period may be a problem.

The principal shortcoming of the technique is that the data presented are for total particulate, which in general are of less interest than TSP or IP data.

The upwind-downwind source depletion data which indicated source enhancement in the majority of tests was misleading. Poor results have been attributed to three main causes.

First, many of the sources tested by upwind-downwind required placement of the first row of samplers at relatively large distances from the source (30-60 m compared to 5-10 profiling). A large part of the deposition may already have occurred prior to this first distance, resulting in apparent emission rates of about the same magnitude at the four downwind distances, rather than decreasing with distance from an emission rate measured immediately downwind of the source.

The second suspected cause was that reentrainment may actually be increasing downwind concentrations. Most of the source listed in Table 12-4 were, by necessity, tested with the samplers placed on recently-disturbed surfaces adjacent to the sources. Haul roads were an exception, in that stable vegetated areas adjacent to the roads could be selected as sampling locations.

The third suspected cause of an upward bias in emission rates with distance was the point source dispersion equation. If equivalent data are input to the point and line source dispersion equations, the line source version will usually indicate a greater reduction in apparent emission rates with distance. The sensitivity of calculated emission rates to several parameters in the point source equation but not in the line source equation were evaluated, but no single parameter was isolated that could be masking the reduction in apparent emission rates with increase in distance.

Because of these three identified problems, it is recommended that additional deposition measurements be made on line sources where reentrainment near downwind samplers is minimized.

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ESTIMATED EFFECTIVENESS OF CONTROL MEASURES

Two control measures for unpaved roads and mine areas were tested as part of this study. The controls were calcium chloride/watering and watering only. Table 12-5 summarizes the results obtained. No control cost data were obtained.

At Mine 1, two tests of an unpaved access road treated with calcium chloride were performed. According to plant personnel, calcium chloride (Dow Peladow) had been applied at a density of 0.6 gallon of 30 percent solution per square yard of road surface, approximately three months prior to testing. This road was watered four times each day to maintain the effectiveness of the calcium chloride. Watering occurred about one hour before testing, but no rewatering was done during a test. Three tests of an uncontrolled access road at Mine 1 were performed to establish the uncontrolled emission rate for the calculation of control efficiency. As indicated in Table 12-5, the control efficiency calculated from the average controlled and uncontrolled emission rates was 95 percent for SP and IP and 88 percent for FP.

At Mine 2, four tests of a watered haul road and four tests of the same road without watering were performed to determine the control efficiency of watering. The measured watering rate was 0.05 gallon per square yard of road surface about 5 minutes prior to start of sampling. No rewatering was done during testing. As indicated in Table 12-5, a mean control efficiency of approximately 60 percent was achieved, with no appreciable dependence on particle size. A similar series of tests performed at Mine 3 to determine the effectiveness of haul road watering yielded a mean control efficiency of about 70 percent. Watering of the loading areas at Mine 3 reduced coal loading emissions an average of 78, 81, and 68 percent for TSP, IP, and FP, respectively.

Although no quantitative data on the effectiveness of calcium chloride as a dust control measure for unpaved roads was found in the literature, references were found that contained data evaluating watering as a dust control measure for haul roads. The estimated control efficiency of 50 percent for watering, as reported by Jutze and Axetell (1974), has been cited in several recent primary references on fugitive dust control. Actual test data reported on watering of haul roads in surface coal mines (U.S. Environmental Protection Agency 1978a) showed a control efficiency value of 31 percent was reported (PEDCo Environmental 1980) for watering of haul roads in a stone quarry.

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TABLE 12-5. CALCULATED EFFICIENCIES OF CONTROL MEASURES

Source	Control measure	SP[a]/IP/FP	Measured emission rates, lb/VMT[b]		Mean control efficiency, %
			Uncontrolled	Controlled	
Access road (Mine 1)	Calcium chloride	SP	5.5, 8.2, 6.7	0.35	95
		IP	4.5, 6.6, 5.2	0.34	95
		FP	0.50, 1.5, 0.22	0.09	88
Haul road (Mine 2)	Watering	SP	6.4, 4.4, 4.5, 6.0	2.2, 2.5, 0.60, 3.4	59
		IP	3.3, 2.3, 2.3, 3.2	1.1, 1.3, 0.40, 1.8	61
		FP	0.15, 0.18, 0.19, 0.23	0.07, 0.10, 0.10, 0.06	58
Haul road (Mine 3)	Watering	SP	20.6, 6.3, 24.1, 14.1	5.1, 1.8, 8.4, 4.3, 5.6	69
		IP	14.7, 3.2, 11.5, 6.3	2.2, 1.0, 4.1, 2.1, 2.5	73
		FP	0.29, 0.20, 0.14	0.05, 0.11, 0.15, 0.10, 0.07	54
Coal loading (Mine 3)	Watering	TSP	0.120, 0.082, 0.193, 0.358, 0.188	0.051, 0.010, 0.009, 0.014, 0.035, 0.062, 0.058, 0.095, 0.042	78
		IP	0.044, 0.008, 0.038 0.121	0.016, 0.002, 0.001, 0.006, 0.008, 0.012, 0.014, 0.020, 0.011	81
		FP	0.0038, 0.0005, 0.0033 0.0035	0.0022, 0.0002, 0.0001, 0.0001, 0.0012, 0.0012, 0.0005, 0.0005, 0.0021	68

[a] SP is the <30 μm fraction, approximately equal to TSP.

[b] Emission factors for coal loading are expressed in units of lb/ton.

The efficiency values for watering of haul roads obtained in this study (Table 12-5) were higher than the previously reported values and the original estimate of 50 percent. The efficiency values for calcium chloride are consistent with reported values of initial control efficiency exceeding 90 percent for other chemical treatment measures: lignin sulfonate applied to haul roads in a taconite mine and petroleum resin applied to a steel plant road (Cowherd, et al. 1979).

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SECTION 13

DEVELOPMENT OF CORRECTION FACTORS AND EMISSION FACTOR EQUATIONS

The method for developing correction factors was based on multiple linear regression (MLR), as described in Section 5. To summarize the method briefly, values for all variables being considered as possible correction factors were tablulated by source with the corresponding TSP emisison rates for each test, then the data were transformed to their natural logarithms. The transformed data were input to the MLR program, specifiying the stepwise option and permitting entry of all variables that increased the multiple regression coefficient (initially allowing the program to determine the order of entry of the variables).

The MLR output of greatest interest with the significance of each variable. In nontechnical terms, significance is the probability that the observed relationship between the independent and dependent variables is due to chance. If the significance was less than 0.05, the variable was included as a correction factor; if it was between 0.05 and 0.20 , its inclusion was discretionary; and if above 0.20, the variable was not included. The correction factors were multiplicative because of the ln transformation; the power for each significant correction factor was specified in the MLR output as the coefficient (B value) for that variable in the linear regression equation.

This MLR analysis could not be employed with data from the wind erosion sources because sequential tests were found to be related and were grouped, thus reducing the number of independent data points. With the large number of potential correction parameters in relation to data points, regression analysis was not feasible.

MULTIPLE LINEAR REGRESSION ANALYSIS

The stepwise multiple linear regresssion program that is the nucleus of the correction factor deveopment procedure is explained in moderate detail in Appendix A. Further information on it can be found in the following three references: Statistical Methods, Dourth Edition (Snedecor 1946); Applied Regression Analysis (Draper and Smith 1965); and SPSS, Second Edition (Nie 1975).

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The independent variables that were evaluated as possible correction factors are listed in Table 13-1. An assessment was made during the MLR analysis to determine the portion of the total variation in the emission factors explained by the correction factors (multiple regression coefficient squared) and whether additional variables should have been considered. The data for each of these variables were presented in tables throughout Sections 7 through 11, and have not been repeated here.

The data were all transformed to their natural logarithms prior to running MLR. The presumption that the ln transformation would provide better final emission factor equations was based on three considerations: the data sets all had high relative standard deviations indicating that the distributions of the emission factor were skewed to the right (i.e., a long upper tail); the homogeneity of variances (a condition for any least squares analysis) was increased; and multiplicative correction factors were preferable to additive ones.

More than one MLR was usually required to obtain the final MLR equations with its associated significance and regression coefficients (B values). Second and third runs were neeeded to eliminate a data point shown to be an outlier, to remove a variable highly correlated with another, to remove a variable with significance of 0.05 to 0.20 that entered the stepwise regression ahead of another variable still being evaluated, or to eliminate a dummy variable (such as a source subcategory or control/no control) after its significant had been determined. The sequence of MLR runs with the TSP data for each source is documented by presenting in Table 13-2 the results of the first run for each source (with all the variables included), a description in Table 13-3 of all changes made to get to the final run, and in Table 13-4 the results of the final run.

The multiple regression (correlation) coefficient, R, is a measure of how well the variables in the equation explain variations in emission rate. (Actually, R^2 is the portion of the total variation explained by the use of the specified variables). Significance, the second reported statistic, estimates the change that the observed correlation for a particular variable is due to random variation. Finally, the residual relative standard deviation measures the amount of variability left in the transformed data set after adjustment as indicated by the regression equation. In the transformed data set, the mean logarithmic values can be quite small. Consequently, the relative standard deviations are larger than normally encountered in regression analysis.

Several independent variables were fairly significant (less than 0.20) when they entered the regression equations, but were not included as correction factors in the final emission factors. The reasons for omitting these potential correction factors are explained below, by source:

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TABLE 13-1. VARIABLES EVALUATED AS CORRECTION FACTORS

Source	Sample size[a]	Variables evaluated	Units
Drill, overburden	30	Silt	%
		Moisture	%
		Depth of drilling	ft
Blasting	18	Material blasted (coal or overburden)	-
		No. of holes	-
		Area blasted	ft^2[b]
		Depth of holes	ft
		Moisture	%
		Distance to samplers	m
		Wind speed	m/s
		Stability class	-
Coal loading	25	Equipment type	-
		Bucket size	yd^3
		Moisture	%
Dozer	27	Material worked	-
		Dozer speed	mph
		Silt	%
		Moisture	%
		Wind speed	m/s
Dragline	19	Drop distance	ft
		Bucket size	yd^3
		Silt	%
		Moisture	%
Scrapers	15	Silt	%
		Weight	tons[b]
		Vehicle speed	mph
		Wheels	-
		Silt loading	g/m^2
		Moisture	%
		Wind speed	m/s
Graders	7	c	c
Light- and medium-duty vehicles	10	c	c
Haul trucks	27	c	c

[a] Uncontrolled runs only.

[b] Originally reported in metric units the variable values were converted to english units.

[c] Same as for scrapers.

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TABLE 13-2. RESULTS OF FIRST MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Variable (in order of MLR output)	Multiple R	Signif- icance	Rel. std. dev.
				9.54
Drill	Silt	0.51	0.004	8.35
	Moisture	0.53	0.421	8.40
	Depth	0.53	0.719	8.54
				0.515
Blasting, all	Area blasted	0.73	0.001	0.363
	Moisture	0.79	0.077	0.337
	Depth of holes	0.90	0.002	0.246
	Wind speed	0.91	0.248	0.242
	No. of holes	0.93	0.163	0.232
	Material blasted	0.93	0.300	0.230
	Dist. to samplers	0.94	0.589	0.238
	Stability class	0.94	0.910	0.250
				0.596
Blasting, coal[a]	Moisture	0.82	0.000	0.353
	Areas blasted	0.90	0.022	0.287
	Wind speed	0.92	0.143	0.269
	No. of holes	0.94	0.123	0.247
	Depth of holes	0.94	0.608	0.257
	Stability class	0.94	0.523	0.267
	Dist. to samplers	0.95	0.662	0.283
				0.414
Coal loading, all	Equipment type	0.74	0.000	0.287
	Moisture	0.77	0.097	0.275
	Bucket size	0.89	0.000	0.203
				0.492
Coal loading, front-end loader[a]	Moisture	0.80	0.000	0.306
	Watering	0.90	0.001	0.230
				0.762
Dozer, all	Material worked	0.66	0.000	0.582
	Moisture	0.91	0.000	0.331
	Silt	0.92	0.040	0.308
	Dozer speed	0.95	0.004	0.260
	Wind speed	0.95	0.477	0.263
				0.458
Dozer, coal[a]	Silt	0.97	0.000	0.112
	Moisture	0.98	0.139	0.103
	Dozer speed	0.98	0.625	0.108

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TABLE 13-2 (continued)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. std. dev.
				0.867
Dozer, overburden[a]	Moisture	0.78	0.001	0.566
	Silt	0.87	0.029	0.471
	Dozer speed	0.91	0.072	0.417
				0.416
Dragline	Drop distance	0.74	0.000	0.288
	Moisture	0.85	0.004	0.229
	Silt	0.86	0.365	0.230
	Bucket size	0.87	0.147	0.236
				0.526
Scrapers (all uncontrolled)	Weight	0.68	0.022	0.407
	Moisture	0.80	0.076	0.350
	Wheels	0.85	0.232	0.336
	Silt	0.94	0.028	0.235
	Vehicle speed	0.96	0.187	0.212
	Silt loading	0.97	0.318	0.206
	Wind speed	0.97	0.794	0.235
				16.933
Graders (all uncontrolled)[b]	Silt loading	0.40	0.500	17.909
	Vehicle speed	0.63	0.471	18.614
	Wheels	0.96	0.226	9.144
				6.562
Light- and medium-duty vehicles (all uncontrolled)[c]	Moisture	0.97	0.000	1.741
	Weight	0.99	0.005	1.019
	Wheels	0.99	0.349	1.017
	Silt	0.99	0.681	1.093
	Silt loading	1.00	0.133	0.890
	Wind speed	1.00	0.202	0.749
				0.788
Haul trucks (includes uw.-dw. tests, all uncontrolled)	Vehicle speed	0.51	0.011	0.693
	Wind speed	0.72	0.003	0.573
	Moisture	0.89	0.000	0.390
	Silt loading	0.91	0.039	0.357
	Wheels	0.91	0.701	0.365
	Weight	0.92	0.318	0.364
	Silt	0.92	0.886	0.375

[a] This source was evaluated initially as a subset of the entire data set and was not carried through the subsequent data analyses.

[b] Weight, moisture, silt, and wind speed were rejected in the first MLR because of an insufficient tolerance level.

[c] Vehicle speed was rejected because of an insufficient tolerance level.

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TABLE 13-3. CHANGES MADE IN MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Change made	Run No.	Reason
Drill	Remove two data points	2	Outliers
Blasting, all	Specify moisture as first variable	2	Moisture had R = 0.72 vs. area with R = 0.73
Coal loading, all	Eliminate bucket size, add control	2	Bucket size was to the 12.3 power
	Remove one data point	3	Outlier
Dozer, all	Remove one data point	2	Outlier
Dragline	Remove one data point	2	Outlier
Scraper	Drop wheels, moisture, and silt loading	2	Wheels did not vary appreciably, moisture and silt loading difficult to quantify
	Add moisture; remove anisokinetic runs; drop wind	3	Moisture needs to explain low emissions at mine. Four anisokinetic runs (low winds) eliminated
Graders	Drop wheels, weight, moisture, and silt loading	2	Wheels and weight did not vary appreciably, moisture and silt loading difficult to quantify
Light- and medium-duty vehicles			
Haul trucks	Drop wind speed, vehicle speed, anisokinetic runs	2	Three anisokinetic runs (low winds) eliminated, vehicle speed correlation inconsistent with previous studies
	Remove K-7 and L-1	3	Outlier and run unrepresented by vehicle mix

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TABLE 13-4. RESULTS OF FINAL MULTIPLE LINEAR REGRESSION RUNS (TSP)

Source	Variable	Multiple R	Significance	Rel. std. dev.
				5.30
Drill	Silt	0.59	0.001	4.36
				0.515
Blasting, all	Moisture	0.72	0.001	0.367
	Depth	0.84	0.009	0.300
	Area	0.90	0.012	0.246
				0.341
Coal loading, all	Moisture	0.67	0.000	0.258
	Control	0.77	0.012	0.227
				0.774
Dozer, all	Material worked	0.67	0.000	0.587
	Moisture	0.93	0.000	0.298
	Silt	0.95	0.005	0.253
	Dozer speed	0.97	0.003	0.210
				0.389
Dragline	Drop distance	0.80	0.000	0.241
	Moisture	0.91	0.001	0.172
	Silt	0.93	0.043	0.153
				0.647
Scrapers	Silt	0.70	0.036	0.494
	Weight	0.93	0.006	0.271
	Vehicle speed	0.96	0.111	0.225
	Moisture	0.96	0.634	0.243
				2.013
Graders	Vehicle speed	0.83	0.022	1.237
	Wind speed	0.87	0.333	1.212
	Silt	0.90	0.451	1.252
				6.562
Light- and medium-duty vehicles	Moisture	0.97	0.000	1.741
	Weight	0.99	0.005	1.019
	Wheels	0.99	0.349	1.017
	Silt	0.99	0.681	1.093
	Silt loading	1.00	0.133	0.890
	Wind speed	1.00	0.202	0.749
				0.540
Haul trucks	Wheels	0.66	0.002	0.416
	Silt loading	0.72	0.146	0.400
	Weight	0.80	0.036	0.355
	Silt	0.82	0.324	0.355
	Moisture	0.82	0.458	0.360

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Drills/Silt - This variable was highly significant but was inversely rather than directly related to emission rate. Therefore, the last potential correction factor for this source is eliminated; the reported emission factor is simply the geometric mean of the observed values.

Blasts/ No. of holes - This variable was highly correlated with another independent variable, area blasted, which entered the regression equation before number of holes.

Coal loading/Bucket size - Bucket size was related to emission rate by a power of -12.3 in the regression equation, primarily because of the very narrow range of bucket sizes tested--14 to 17 yd^3. Also, bucket size only had a correlation of 0.05 with emission rate.

Dozer, all/Dozer speed - Although equipment speed was significant in the combined data set, it was not significant in either of the subsets (coal dozers or overburden dozers).

Dragline/Silt - In the first run, silt was not a significant variable. However, when an outlier was removed, it became highly significant but was inversely rather than directly related to emission rate

Scrapers/Vehicle speed - This parameter was significant at the 0.111 level, in the discretionary range. It was omitted because of its high correlation with silt which entered the equation earlier.

Light- and medium-duty vehicles/Weight - This was omitted to preserve the simplicity of the resulting equation in light of the high correlation between emission factor and moisture, the first parameter entered.

Haul trucks/Vehicle speed - Inverse relationship with emission rate was inconsistent with all previous studies.

Haul trucks/Weight - This parameter was omitted because it coefficient was negative, which is difficult to justify from the physics of the problem.

These relationships conflicted with previous experience in fugitive dust testing . While the actual relationship may be similar to that indicated by the MLR equation, some confirmation in the form of additional data was thought to be needed before including these dubious parameters as correction factors.

The transformations, initial MLR runs, adjustments, and additional MLR runs were done by the same procedures with the IP emission data as with the TSP data, using the same values of the independent variables.

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The results are summarized in an analogous series of three tables--Tables 13-5, 13-6 and 13-7. As indicated in Table 13-6, very few changes were required from the initial runs of the IP data, with the benefit of the prior TSP runs. For every source, the same independent variables were highly significant for IP as for TSP.

EMISSION FACTOR PREDICTION EQUATIONS

The prediction equations obtained from the MLR analyses are summarized in Table 13-8. These equations were taken directly fro mthe MLR runs described in Tables 13-4 and 13-7, with the coefficients in the Table 13-8 equations being the exponentials of the MLR equation constant terms and the exponents for each term being the B values. These equations give estimates of the median value of the emission factors for given value(s) of the correction factor(s). (The coefficients and exponents are from the intermediate MLR step that includes only the significant variables that appear in the final equation.) All but four of the independent variables in the equations in Table 13-8 are significant at the 0.05 level or better. The four variables in the discretionary range (0.05 to 0.20) that were included are: L in haul truck TSP equation, a = 0.146; A in the coal blasting IP equation, a = 0.051; M in the overburden IP equation, a = 0.71; and S in the grader IP equation, a = 0.078. The geometric mean values and ranges of the correction factors are summarized in Table 13-9.

CONFIDENCE AND PREDICTION INVERVALS

A computational procedure for obtaining confidence and prediction intervals for emission factors is described in Appendix B at the end of this volume of the report. An example of this computation is given here for coal loading emission data versus the moisture content correction factor.

Figure 13-1 summarizes the results of this example and also includes the observed emission factors. The line in the center of the graph is the predicted median emission rate estimated by the goemetric mean. The inside set of curves give the confidence interval for the "true median" as a function of moisture content (M), and the outside set of curves give the prediction interval for an individual emission factor. The intervals vary in length as a function of M. The widths of the intervals are measures of the precision of the estimated factors. These precisions are comparable to those of existing emission factors as illustrated in Section 14.

TABLE 13-5. RESULTS OF FIRST MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Variable (in order of MLR output)	Multiple R	Significance	Rel. std. dev.
Drill	N/A			9.54
				0.753
Blasting, all	Moisture	0.81	0.015	0.367
	Depth of holes	0.88	0.040	0.330
	Area blasted	0.92	0.000	0.451
	Wind speed	0.93	0.210	0.321
	No. of holes	0.94	0.225	0.312
	Material blasted	0.95	0.272	0.307
	Dist. to samplers	0.95	0.313	0.305
	Stability class	0.95	0.841	0.323
				0.933
Blasting, coal[a]	Moisture	0.86	0.000	0.490
	Areas blasted	0.91	0.050	0.421
	No. of holes	0.93	0.146	0.392
	Wind speed	0.94	0.202	0.373
	Dist. to samplers	0.96	0.248	0.360
	Stability class	0.96	0.489	0.373
				0.235
Coal loading, all	Moisture	0.49	0.017	0.210
	Control	0.66	0.017	0.185
	Equipment type	0.67	0.576	0.189
				1.569
Dozer, all	Material worked	0.71	0.000	1.132
	Moisture	0.91	0.000	0.683
	Silt	0.94	0.006	0.579
	Dozer speed	0.97	0.001	0.449
				0.682
Dozer, coal[a]	Moisture	0.91	0.000	0.291
	Silt	0.96	0.012	0.213
	Dozer speed	0.96	0.420	0.216
				8.262
Dozer, overburden[a]	Silt	0.77	0.004	5.550
	Moisture	0.85	0.071	4.830
	Dozer speed	0.87	0.290	4.756
				0.259
Dragline	Moisture	0.49	0.032	0.232
	Drop distance	0.69	0.015	0.197
	Silt	0.72	0.281	0.196
	Bucket size	0.73	0.582	0.200

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TABLE 13-5 (continued)

Source	Variable (in order of MLR output)	Multiple R	Signif-icance	Rel. std. dev.
				0.987
Scrapers (all uncontrolled)	Weight	0.71	0.015	0.735
	Moisture	0.81	0.094	0.647
	Wheels	0.86	0.173	0.600
	Silt	0.93	0.058	0.469
	Vehicle speed	0.96	0.086	0.371
	Silt loading	0.98	0.238	0.341
	Wind speed	0.98	0.737	0.386
				0.906
Graders (all uncontrolled)	Silt	0.30	0.626	0.998
	Wheels	0.65	0.397	0.975
	Silt loading	0.87	0.442	0.883
				1.977
Light- and medium-duty vehicles (all uncontrolled)	Silt loading	0.97	0.000	0.526
	Silt	0.98	0.043	0.410
	Vehicle speed	0.99	0.010	0.243
	Wind speed	1.00	0.044	0.170
				1.991
Haul trucks (includes uw.-dw. tests, all uncontrolled)	Vehicle speed	0.40	0.046	1.861
	Wind speed	0.64	0.006	1.600
	Moisture	0.84	0.000	1.153
	Silt loading	0.84	0.695	1.177
	Wheels	0.84	0.754	1.205
	Weight	0.85	0.609	1.228
	Silt	0.85	0.724	1.259

[a] This source was evaluated initially as a subset of the entire data set and was not carried through the subsequent data analyses.

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TABLE 13-6. CHANGES MADE IN MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Change made	Run No.	Reason
Blasting, all	None		
Coal loading, all	None		
Dozer, all	Remove one data point	2	Outlier
Dragline	None		
Scrapers	Drop wheels, silt loading, wind speed; remove anisokinetic runs	2	Wheels did not vary appreciably, silt loading difficult to quantify; four anisokinetic runs (low winds) eliminated
Graders	Drop wheels, weight, moisture, and silt loading	2	Wheels and weight did not vary appreciably; moisture and silt loading difficult to quantify
Light- and medium-duty vehicles	None		
Haul trucks	Drop wind speed, vehicle speed; remove anisokinetic runs plus K-7 and L-1	2	Three anisokinetic runs (low winds) eliminated. Vehicle speed correlation inconsistent with previous studies. L-1 is outlier and K-7 had unrepresentative vehicle mix

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TABLE 13-7. RESULTS OF FINAL MULTIPLE LINEAR REGRESSION RUNS (IP)

Source	Variable	Multiple R	Significance	Rel. std. dev.
				0.753
Blasting, all	Moisture	0.81	0.000	0.451
	Depth of holes	0.88	0.015	0.376
	Area blasted	0.92	0.040	0.330
				0.235
Coal loading, all	Moisture	0.49	0.017	0.210
	Control	0.66	0.017	0.185
				1.676
Dozer, all	Material worked	0.70	0.000	1.230
	Moisture	0.92	0.000	0.696
	Silt	0.95	0.006	0.583
	Dozer speed	0.98	0.000	0.405
				0.259
Dragline	Moisture	0.49	0.032	0.232
	Drop distance	0.69	0.015	0.197
				1.706
Scrapers	Silt	0.67	0.046	1.346
	Weight	0.90	0.015	0.856
	Vehicle speed	0.96	0.036	0.580
				3.439
Graders	Vehicle speed	0.70	0.078	2.680
	Wind speed	0.81	0.246	2.478
	Silt	0.89	0.254	2.220
				1.977
Light- and medium-duty vehicles	Moisture	0.95	0.000	0.667
	Weight	0.99	0.005	0.389
	Silt	0.99	0.084	0.321
	Vehicle speed	0.99	0.217	0.298
	Silt loading	1.00	0.161	0.253
	Wind speed	1.00	0.216	0.216
				1.043
Haul trucks	Wheels	0.65	0.003	0.816
	Weight	0.68	0.272	0.809
	Silt loading	0.72	0.198	0.790
	Silt	0.73	0.617	0.810
	Moisture	0.74	0.473	0.823

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TABLE 13-8. PREDICTION EQUATIONS FOR MEDIAN EMISSION RATES

Source	Prediction equations TSP	Prediction equations IP	FP/TSP ratios median value	Units
Drill	1.3	None[a]	None[a]	lb/hole
Blasting, all	$\frac{961\ A^{0.8}}{D^{1.8}\ M^{1.9}}$	$\frac{2550\ A^{0.6}}{D^{1.5}\ M^{2.3}}$	0.030	lb/blast
Coal loading	$1.16/M^{1.2}$	$0.119/M^{0.9}$	0.019	lb/ton
Dozer, all				
Coal	$78.4\ s^{1.2}/M^{1.3}$	$18.6\ s^{1.5}/M^{1.4}$	0.022	lb/h
Overburden	$5.7\ s^{1.2}/M^{1.3}$	$1.0\ s^{1.5}/M^{1.4}$	0.105	lb/h
Dragline	$0.0021\ d^{1.1}/M^{0.3}$	$0.0021\ d^{0.7}/M^{0.3}$	0.017	lb/yd^3
Scrapers	$(2.7\text{x}10^{-5})s^{1.3}W^{2.4}$	$(6.2\text{x}10^{-6})s^{1.4}W^{2.5}$	0.026	lb/VMT
Graders	$0.040\ S^{2.5}$	$0.051\ S^{2.0}$	0.031	lb/VMT
Light- and medium-duty vehicles	$5.79/M^{4.0}$	$3.72/M^{4.3}$	0.040	lb/VMT
Haul trucks	$0.0067\ w^{3.4}L^{0.2}$	$0.0051\ w^{3.5}$	0.017	lb/VMT

[a] Test method allowed for measurement of TSP only.

s = silt content, %
A = area blasted, ft^2
D = depth of holes, ft
M = moisture content, %
d = drop distance, ft

W = vehicle weight, tons
S = vehicle speed, mph
w = number of wheels
L = silt loading, g/m^2

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TABLE 13-9. TYPICAL VALUES FOR CORRECTION FACTORS

Source	Correction factor	GM[a]	Range[b] Min.	Range[b] Max.	Units
Blasting	Moisture	17.2	7.2	38	Percent
	Depth	25.9	20	135	Ft
	Area	18,885	1076	103,334	Ft^2
Coal loading	Moisture	17.8	6.6	38	Percent
Dozers, coal	Moisture	10.4	4.0	22.0	Percent
	Silt	8.6	6.0	11.3	Percent
ovb.	Moisture	7.9	2.2	16.8	Percent
	Silt	6.9	3.8	15.1	Percent
Draglines	Drop distance	28.1	5	100	Ft
	Moisture	3.2	0.2	16.3	Percent
Scrapers	Silt	16.4	7.2	25.2	Percent
	Weight	53.8	36	70	Tons
Graders	Speed	7.1	5.0	11.8	mph
Light- and medium-duty vehicles	Moisture	1.2	0.9	1.7	Percent
Haul trucks	Wheels	8.1	6.1	10.0	Number
	Silt loading	40.8	3.8	254.0	g/m^2

[a] GM = antilog $\overline{\{\ln (\text{correction factor})\}}$, that is, the antilog of the average of the ln of the correction factors.

[b] Range is defined by minimum (Min.) and maximum (Max.) values of observed correction factors.

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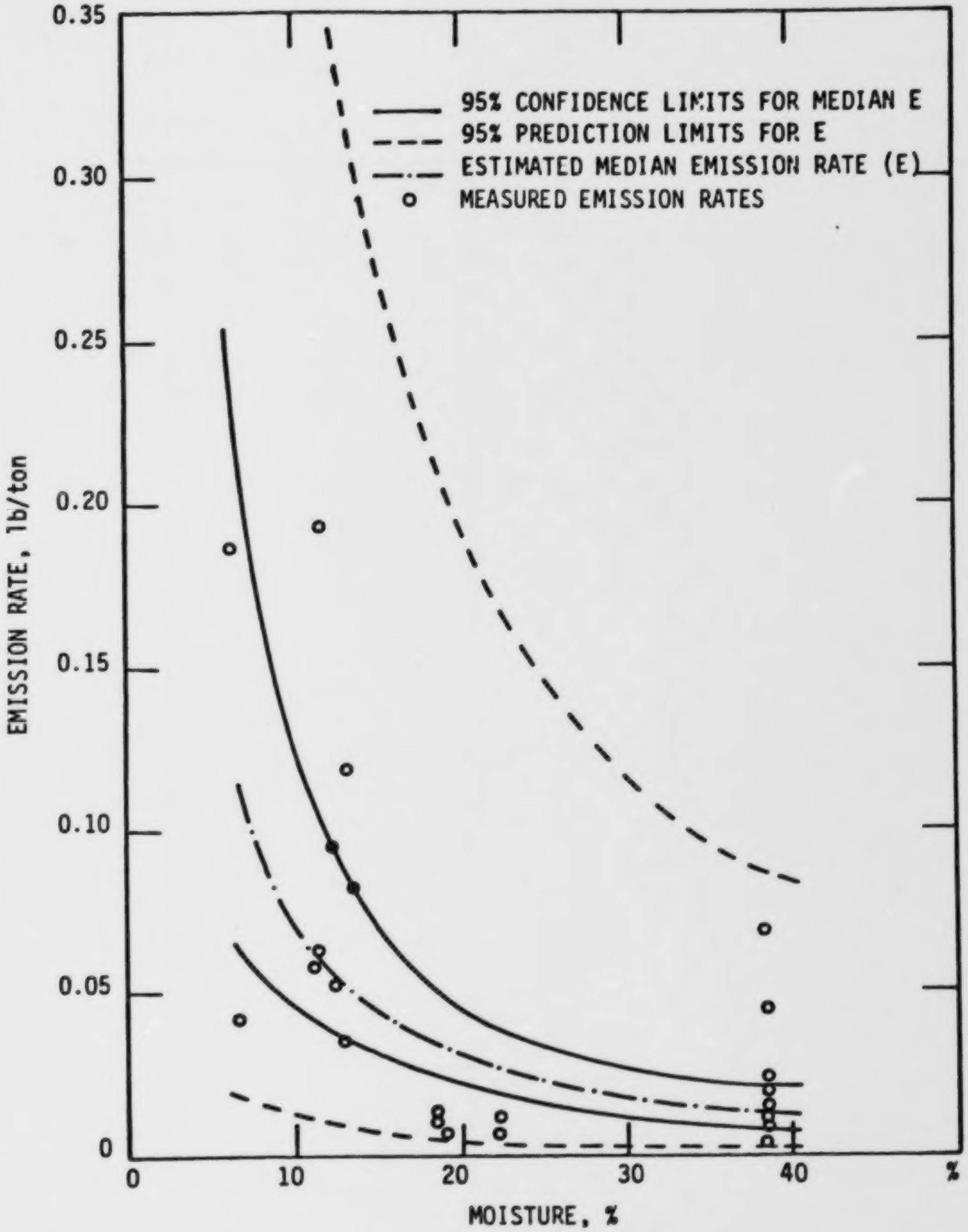

Figure 13-1. Confidence and prediction intervals for emission factors for coal loading.

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To summarize the information contained in these curves for confidence intervals, the following information is presented:

1. Prediction equation for the median emission factor from Table 13-8: TSP, lb/ton = $1.16M^{1.2}$.

2. Geometric mean and range (maximum and minimum values) of moisture content correction factor from Table 13-9: GM = 17.8 percent, 6.6 to 38 percent.

3. Estimated median emission factor at the geometric mean (GM) of the correction factor from Table 13-10: 0.034 lb/ton.

4. Ninety-five percent confidence intervals for the median emission factor (the median value for a large number of tests over one year) at the GM of each correction factor from Table 13-10: 0.023 lb/ton to 0.049 lb/ton.

5. Ninety-five percent prediction intervals for an individual emission factor (approximately one hour) at the GM of the correction factor from Table 13-10: 0.005 lb/ton to 0.215 lb/ton.

The confidence and prediction interval data are given only for one value of the correction factor(s) in order to simplify the presentation. The widths of the intervals of the GM are indicative of the widths at other values provided one uses a percentage of the median value in deriving the confidence and prediction limits. For example, for the coal loading data the lower confidence limits are approximately 50 to 70 percent of the median value, the upper limits are 140 to 170 percent of the median value; the lower prediction limits are 15 percent of the median value and the upper limits are 630 percent (or 6.3 times) of the median value. The coal loading data are slightly more variable than data for other sources and hence the limits are proportionately wider than for the other sources.

Fine particulate (FP) emission factors were not developed by the same series of steps as were the TSP and IP factors, because of the larger variances expected in these data sets and the many tests with negligible readings. However, the relative standard deviations calculated from data in Table 12-2 indicate variability approximately the same as for TSP and IP data. The geometric mean ratios of FP to TSP presented in Table 13-8 are proposed for use with the TSP emission factor equations to derive FP emission factors. The FP emission factor is obtained by multiplying the median FP/TSP ratio times the calcualted TSP emission factor for each source.

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TABLE 13-10. EMISSION FACTORS, CONFIDENCE AND PREDICTION INTERVALS

Source	TSP/IP	Emission factor,[a] median value	Units	95% confidence interval for median LCL[b]	UCL[b]	95% prediction interval for emission factor LPL	UPL
Drills	TSP	1.3	lb/hole	0.8	2.0	0.1	12.7
Blasting, all	TSP	35.4	lb/blast	22.7	55.3	5.1	245.8
	IP	13.2		8.5	20.7	2.0	87.9
Coal loading, all	TSP	0.034	lb/ton	0.023	0.049	0.005	0.215
	IP	0.008		0.005	0.013	0.001	0.071
Dozers, all coal	TSP	46.0	lb/h	35.5	59.6	18.1	117.0
	IP	20.0		13.2	30.4	4.5	90.2
ovb.	TSP	3.7	lb/h	2.6	5.3	0.91	15.1
	IP	0.88		0.59	1.3	0.21	3.7
Draglines	TSP	0.059	lb/yd^3	0.046	0.075	0.020	0.170
	IP	0.013		0.009	0.020	0.002	0.085
Lt.- and med.-duty vehicles	TSP	2.9	lb/VMT	2.3	3.9	1.35	6.4
	IP	1.8		1.6	2.0	0.64	5.0
Graders	TSP	5.7	lb/VMT	3.2	9.9	1.14	28.0
	IP	2.7		1.4	5.3	0.39	18.5
Scrapers	TSP	13.2	lb/VMT	10.0	17.7	5.2	33.1
	IP	6.0		4.3	8.9	1.8	20.2
Haul trucks	TSP	17.4	lb/VMT	12.8	23.4	4.3	68.2
	IP	8.2		5.7	11.0	1.8	33.7

[a] These exact values from the MLR output are slightly different than can be obtained from the equations in Table 13-8 and the correction factor values in Table 13-9 due to the rounding of the exponents to one decimal place.

[b] LCL denotes lower confidence limit. UCL denotes upper confidence limit.

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EMISSION FACTORS FOR WIND EROSION SOURCES

In nearly all of the tests of of wind erosion emissions from the surface of coal piles and exposed ground areas, the SP and IP emission rates were found to decay sharply with time. An exception was the sandy topsoil tested at Mine 3; in that case, an increase in emission rate was observed, probably because of the entrainment effect of infiltration air as the loose soil surface receded below the sides of the wind tunnel. The concept of erosion potential was introduced in Section 5 to treat the case of an exponentially decreasing quantity of erodible material on the test surface. The erosion potential is the total quantity of particles, in any specified particle size range, present on the surface (per unit area) that can be removed by erosion at a particular wind speed.

The calculation of erosion potential necessitated grouping of sequential tests on the same surface. In effect, this reduced the number of independent data points for coal and overburden emissions from 32 to 16. As a result, the decision was made not to subject these data to regression analysis because of the large number of potentially significant correction parameters in relation to the number of emission measurements for any given surface type and condition.

Table 13-11 lists the calculated values of erosion potential classified by erodible surface type and by wind speed at the tunnel centerline. For the most part, the test wind speeds fit into 3-mph increments; values of erosion potential for the few runs performed at other wind speeds are listed under the nearest wind speed category. Whenever erosion potential is given as a range, the extremes represent two data points obtained at nominally the same conditions.

Erosion potential was calculated using Equation 22 (Chapter 5), which is repeated here:

$$\frac{\ln\left(\frac{M_o - L_1}{M_o}\right)}{\ln\left(\frac{M_o - L_2}{M_o}\right)} = \frac{t_1}{t_2} \qquad \text{(Eq. 22)}$$

where

M_o = erosion potential, i.e., quantity of erodible material present on the surface before the onset of erosion, g/m^2.

TABLE 13-11. CALCULATED EROSION POTENTIAL VERSUS WIND SPEED

Surface	Mine	Test series	SP ~~SR~~ Erosion potential, lb/acre				
			26 mph[a]	29 mph[a]	32 mph[a]	35 mph[a]	38 mph[a]
Coal							
Area surrounding pile	1	J-26	> 140[b]				
		J-26 and 27				470[b]	
On pile, uncrusted	2	K-45 and 46		230			
		K-40 and 41			480		
		K-39					550[b]
		K-42 and 43					370
On pile, lightly crusted tracks[c]	3	P-20	68[b]				
		P-31 and 32	30				
		P-20 to 22		140			
		P-20 to 24			260		
		P-31 to 35			130[b]		
On pile furrow	3	P-27 and 28				70	
		P-27 to 30					90
Overburden	2	K-35 and 36				90	
		K-37				40[b]	
Scoria (roadbed material)	2	K-49 and 50				100	

[a] Wind speed measured at a height of 15 cm above the eroding surface.

[b] Estimated value.

[c] Erosion loss may have occurred prior to testing.

t = cumulative erosion time, s

L_1 = measured loss during time period 0 to t_1, g/m^2

L_2 = measured loss during time period 0 to t_2, g/m^2

Alternatively, Equation 22 can be rewritten as follows:

$$\left(1 - \frac{L_2}{M_o}\right) = \left(1 - \frac{L_1}{M_o}\right)^{\frac{t_2}{t_1}} \qquad \text{(Eq. 22a)}$$

An iterative calculation procedure was required to calculate erosion potential from Equation 22 or 22a. Further, two cumulative loss values and erosion times obtained from back-to-back testing of the same surface were required. Each loss value was calculated as the product of the emission rate and the erosion time.

For example, Runs P-27 and P-28 took place on a coal pile furrow at a tunnel centerline wind speed of 36 mph. The incremental losses were calculated as follows:

P-27: 0.0386 g/m^2-s x 120 s = 4.63 g/m^2

P-28: 0.00578 g/m^2-s x 480 s = 2.77 g/m^2

Thus the values substituted into Equation 22 for this test series were:

L_1 = 4.63 g/m^2

t_1 = 120 s

L_2 = 4.63 + 2.77 = 7.40 g/m^2

t_2 = 120 + 480 = 600 s

A value of M_0 = 10 was selected and substituted into the right-hand side of equation 22a and the left-hand side was solved for M_0. The resulting value of 7.75 was then substituted back into the right-hand side to obtain a new solution--7.48. Additional substitutions were made and the iteration procedure converged quickly to 7.46 for erosion potential (M_0), indicating that only a small additional loss (0.06 g/m^2) would have occurred if the tunnel had been operated beyond the 600-s time period at the same wind speed. The corresponding nonmeric value for the erosion potential is 67 lb/acre, which rounds to 70 lb/acre.

Data from unpaired runs (J-26, J-27, K-39, P-20, and K-37) were used to derive estimated values of erosion potential. Except for J-26, the erosion times were long enough so that the measured losses approximated the corresponding erosion potentials.

Note that whenever a surface was tested at sequentially increasing wind speeds, the measured losses from the lower speeds were added to the losses at the next higher speeds and so on. This reflects the hypothesis that, if the lower speeds had not been tested beforehand, correspondingly greater losses would have occurred at the higher speeds.

The emissions from the coal pile at Mine 3 appear to be significantly lower than the coal pile emisisons measured at Mines 1 and 2. the coal pile at Mine 3, which had been inactive for a period of days, was noticeably crusted; but attempts were made to test areas where relativley fresh vehicle tracks were present. It is not known what percentage of the erosion potential of these test areas may have been lost because of brief periods of high winds which typically occurred with the evening wind shift. The coal pile furrow tested at Mine 3 had a much greater portion of large chunks of coal (exceeding 1 inch in size) on the surface, in comparison with the scraper and truck tracks.

The uncrusted overburden and scoria surfaces tested at Mine 2 exhibited emission rates that were much lower than the coal surfaces tested, expect for the coal pile furrow. This reflects the larger portion of nonerodible coarse aggregates present on these non-coal surfaces.

The wind speeds that were used in the testing (Table 13-11), which exceeded the threshold for the onset of visually observable emissions, corresponded to the upper extremes of the frequency distributions of hourly mean wind speeds observed (at a height of 5-10 m) for most areas of the country. For flat surfaces, the wind speed at the centerline of the wind tunnel, 15 cm above the surface, is about half the value of the wind speed at the 10 m reference height. However, for elevated pile surfaces, particularily on the windward faces, the ratio ($u_{15}+u_{ref}$) may approach and even exceed unity. It should be noted that small but measureable erosion may have occurred at the threshold velocity.

In estimating the magnitude of wind generated emisisons, wind gusts must also be taken into account. For the surfaces tested, typically about three-fourths of the erosion potential was emitted within 5 min of cumulative erosion time. Therefore, although the mean wind speeds at surface coal mines will usually not be high enough to produce continuous wind erosion, gusts may quickly deplete the erosion potential over a period of a few hours. Because erosion potential increases rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable which best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement which has passed by the 1-mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 min (for a fastest mile of 30 mph), matches well with the half life of the erosion process, which ranges between 1 and 4 min.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action which results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed ground area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

Although vehicular traffic alters the surface by pulverizing surface material, this effect probably does not restore the full erosion potential, except for surfaces that crust before substantial wind erosion occurs. In that case, breaking of the crust over the area of the tire/surface contact once again exposes the erodible material beneath.

The emission factor for wind generated emissions of a specified particle size range may be expressed in units of lb/acre-month as follows:

$$\text{Emission Factor} = f \cdot P(u^{+}_{15}) \qquad \text{(Eq. 29)}$$

where f = frequency of disturbance, per month

$P(u^{+}_{15})$ = erosion potential corresponding to the observed (or probable) fastest mile of wind for the period between disturbances, after correcting the fastest mile to a height of 15 cm (as described below), lb/acre.

$P(u^{+}_{15})$ is taken directly from Table 13-11 for the type of surface being considered. Interpolation or limited extrapolation of erosion potential data may be required.

When applying Equation 29 to an erodible surface, a modified form of Equation 18 (page 84) is used to correct the fastest mile of wind from the reference anemometer height at the reporting weather station to a height of 15 cm. The correction equation is as follows:

$$u^{+}_{15} = u^{+}_{ref} \quad \frac{\left(\ln \frac{15}{z_o}\right)}{\ln\left(\frac{h_{ref} - h_{surf}}{z_o}\right)} \qquad \text{(Eq. 30)}$$

where u^{+}_{15} = corrected value of the fastest mile, mph

u_{ref} = value of the fastest mile measured at the reference height, mph

h_{ref} = height of the reference anemometer above ground, cm

h_{surf} = height of the eroding surface above ground, cm

z_o = roughness height of the eroding surface, cm

An estimated value of the roughness height for the surface being considered may be obtained from Table 13-12.

Equation 30 is restricted to cases for which $h_{ref} - h_{surf} \geq 15$ cm. Because the standard reference height for meteorological measurement is 10 m, this restriction generally allows for piles as flat upper surfaces as high as about 9.85 m and conical piles as high as 19.7 m. However, there may be situations which do not conform to the above restriction; for example, when the meteorological measurement height is as low as 5 m. As a default value for these cases, u_{15} is set equal to u_{ref}, i.e., no height correction is made for the measured fastest mile.

Values of h_{surf} in Equation 30 reflect the extent to which the eroding surface contour penetrates the surface wind layer. Clearly for flat ground surfaces, $h_{surf} = 0$. For an elevated storage pile with a relatively flat upper surface, h_{surf} represents the height of the upper surface above ground. For conical shaped piles, one-half the pile height is used as a first approximation for h_{surf}. In the case of elevated storage pile surfaces, the emission factor equation (Equation 29) is expressed per unit area of contact between the pile and the ground surface.

To illustrate the application of Equation 29, the following hypothetical example is offered. A coal surge pile planned for a new mine development will have a relatively flat upper surface with an average height of 6 m. The pile will be disturbed at nearly regular intervals every 3 months by adding coal to or removing coal from the surface using trucks and front-end loaders. During periods between disturbance, it is anticipated that light crusting will occur. The fastest mile data for the nearest weather station is shown in Table 13-13, representing a 5-year length of record.

TABLE 13-12. SURFACE AND EMISSION CHARACTERISTICS

Surface	Mine	Roughness height, cm	Threshold speed, mph	IP/SP ratio
Coal				
Area surrounding pile	1	0.01	21	0.62
On pile, uncrusted	2	0.3	25	0.68
On pile, lightly crusted tracks	3	0.06	20	0.55
On pile furrow	3	0.05	33	0.60
Overburden	2	0.3	23	0.68
Scoria	2	0.3	30	0.75

TABLE 13-13. HYPOTHETICAL MONTHLY WIND DATA PRESENTED IN LCD FORMAT

Month	Wind					
	Resultant			Fastest mile		
	Direction	Speed, mph	Avg. speed, mph	Speed, mph	Direction	Date
January	21	0.5	7.8	32	NW	17
February	27	2.2	9.2	34	NW	23
March	27	1.9	10.9	47	N	11
April	04	0.3	8.7	38	S	10
May	17	3.9	10.8	37	SW	18
June	16	2.3	8.9	35	N	26
July	16	1.0	7.9	35	SW	9
August	13	1.4	7.5	31	W	30
September	20	1.9	9.0	45	NW	23
October	17	1.1	7.5	37	NW	7
November	22	0.7	9.2	34	W	26
December	28	2.4	9.1	41	W	24

The height of the reference meteorological instrument is 8.0 m above the ground.

To derive the annual average emisison factor, the year is divided into quarterly periods. The fastest mile for each period is determined, and the average value is calculated. From Table 13-13, the 3-month fastest mile values of 47, 38, 45, and 41 mph yield an average of 43 mph. Next, Equation 30 is used to correct the average fastest mile from the reference height of 8 m to 15 cm above the 6-m height of the upper pile surface. A value of 0.06 cm is used as the roughness height for a lightly crusted coal pile surface, as taken from Table 13-12. Substitution of these data into Equation 30 yields:

$$u^{+}_{15} = 43 \quad \frac{\ln \frac{15}{0.06}}{\ln \frac{800-600}{0.06}} \quad = \quad 29 \text{ mph}$$

From Table 13-11, the SP erosion potential for 29 mph on a lightly crusted coal pile is 140 lb/acre. Substitution into Equation 29 yields:

$$\text{SP emission factor} = \frac{0.33}{\text{mo}} \times 140 \; \frac{\text{lb}}{\text{acre}} = 46 \; \frac{\text{lb}}{\text{acre-mo}}$$

Using the appropriate IP/SP ratio from Table 13-12, the corresponding IP emission factor is 46 x 0.55 = 25 lb/acre-mo.

One notable limitation in the use of Equation 29 is its application to active piles. Because the fastest mile is recorded only once a day, use of the daily fastest mile to represent a surface disturbed more than once per day will result in an over-estimate of emissions.

The approach outlined above for calculation of emission factors appears to be fundamentaly sound, but data limitations produce a large amount of uncertainty in the calculated factors. Even though the erosion potential values are judged to be accurate to within a factor or two or better for the surface tested, it is not known how well these surfaces represent the range of erodible surface conditions found at Western surface coal mines. Additional uncertainty results from the use of Equation 30 to correct the fastest mile values to a height of 15 cm above the erodible surface. Taking all the sources of uncertainty into account, it is thought that the wind erosion emission factors derived for surfaces similar to those tested are accurate to within a factor of about three.

The levels of uncertainty in SP and IP emission factors derived by the technique outlined in this section could be reduced substantially by gathering more data to better define:

1. Relationship of erosion potential to wind speed.
2. Relationship between approach wind speed and the distribution of surface wind speed around basic pile shapes of varying size.
3. Relationship of erosion potential to surface texture.
4. Effect of crusting.

Previous research on wind erosion of natural surfaces could provide some insight into the nature of these effects. Soil loss resulting from wind erosion of agricultural land has been the subject of field and laboratory investigation for a number of years. This research has focused on the movement of total soil mass, primarily sand-sized aggregates, as a function of wind and soil conditions (Bagnold 1941; Chepil and Woodruff 1963). Only relatively recently, however, have field measurements been performed in an effort to quantify fine particle emissions produced during wind erosion of farm fields (Gillette and Blifford 1972; Gillette 1978).

Until further research is accomplished, it is recommended that wind erosion factors be used with full consideration of their uncertainty and preliminary nature. It is recommended that their use be restricted to estimates of emissions relative to other mine sources and that they not be used for estimating the ambient air impact of wind erosion at surface coal mines.

SECTION 14

EVALUATION OF EMISSION FACTORS

COMPARISON WITH PREVIOUSLY AVAILABLE EMISSION FACTORS

As noted in Section of this report, a number of TSP emission factors for surface coal mining operations were available in the published literature prior to this study. However, only those factors reported by the U.S. Environmental Protection Agency (1978a) were based on actual testing in surface coal mines. Other investigators (Cowherd et al. 1979, McCalden and Heidel 1978, and Dyck and Stukel 1976) have reported emission factors for vehicular traffic on unpaved roads expressed in the form of predictive equations. Their factors were not developed with any data from surface coal mines, but were based on field data from unpaved roads of similar characteristics.

Cowherd et al. (1979) used the exposure profiling method to develop a predictive emission factor equation for vehicular traffic on unpaved roads. Their equation was developed from measurement of emissions from a wide range of vehicle types (weighing from 2 to 157 tons) traveling on rural roads, roads at steel plants, and haul roads at a taconite mine.

The emission factor equation developed by McCalden and Heidel (1978) was developed from upwind-downwind tests of light-duty vehicles traveling on five unpaved roads in the Tucson, Arizona area. The downwind samplers were located 50 feet from the test roads.

Dyck and Stukel (1976) used the upwind-downwind sampling method to measure emissions from a single 4-1/2 ton flat-bed truck traveling over access roads at construction site in Illinois. Vehicle weight was varied by placing sand bags on the truck bed. Downwind samplers were located at 50 to 150 feet from the test road.

Table 14-1 compares emission factors from the present study with emission factors reported by EPA and those reported by the other investigators cited above. The factors listed for the present study are medians of the TSP emission factors measured for each source category. The factors listed by EPA (1978a) are averages of those reported for each of the five mines tested.

TABLE 14-1. TSP EMISSION FACTOR COMPARISON

Source	Emission factor, units	TSP emission factor		
		This study[a]	U.S. EPA, 1978a	Other Studies
Drills, ovb.	lb/hole	1.3	1.5	-
Blasting	lb/blast	35.4	55	-
Loading, coal	lb/ton	0.037	0.036	-
Dozers, coal	lb/h	46.0	-	-
Dozers, ovb.	lb/h	3.7	-	-
Dragline	lb/yd^3	0.059	0.027	-
Scrapers	lb/VMT	13.2	-	35.4 (Cowherd et al.1974)
Graders	lb/VMT	5.7	-	6.1 (Cowherd et al.1979)
Light- and medium-duty vehicles	lb/VMT	2.9	-	2.2 (Cowherd et al.1979) 2.9 (McCalden and Heider 1978)
Haul trucks	lb/VMT	17.4	14.1	42.8 (Cowherd et al.1979) 38.0 (Dyck and Stukel 1976)

[a] Geometric mean (GM) emission factor for correction factors at their GM values, Table 13-9.

The other factors listed for unpaved roads were calculated from the respective emission factor equations, using the necessary average correction parameter values obtained in the present study.

In three of five cases, the average emission factor obtained in this study is essentially the same as that reported by EPA in 1978. The factors obtained for access roads are about the same as those calculated from the predictive equations of other investigations. However, the factors obtained in the present study for haul trucks, scrapers, and graders are smaller than those calculated from the predictive equations of other investigators.

STATISTICAL CONFIDENCE IN EMISSION FACTORS

Confidence intervals associated with the emission factors were presented in Table 13-10. They are shown again, expressed as fractions of the corresponding emission factors, in Table 14-2. Also shown in this table are the relative errors predicted in Table 4 of the Second Draft Statistical Plan (June 1980). (For purposes of calculation, the half-width of the confidence interval divided by the median is equal to the relative error.) Comparison of the 80 percent confidence intervals and 20 percent risk level relative errors reveals that the actual confidence intervals were smaller, and therefore better, than the estimated or predicted error levels in 7 out of 10 cases. These results were achieved because correction factors were able to explain a large portion of the sample variance for almost every source.

The confidence intervals as a fraction of the emission factor averaged about -0.20 to +0.24 at the 80 percent confidence level and about -0.30 to +0.43 at the 95 percent confidence level. In comparison, 12 of the most widely used particulate emission factors in EPA's *Compilation of Air Pollutant Emission Factors, AP-42* (1975), had an average 80 percent confidence interval of ±0.28 and an average 95 percent confidence interval of ±0.45, according to a published analysis of AP-42 factors (PEDCo Environmental 1974). Information extracted from Table 2-12 of the published analysis is presented in Table 14-3. Considering the greater variability inherent in emission rates for fugitive dust sources than for most industrial process or combustion sources, the mining emission factors reported herein appear to be on a par with factors in AP-42 that have been given a ranking of A.

With the confidence intervals achieved for all sources, additional sampling using the same techniques to improve precision of one or more factors does not seem to be warranted. However, it should be noted that these emission factors are still limited in their applicability to Western mines and to the ranges of correction parameter conditions over which the present tests were conducted. Also, the number of mines represented is small (only three), hence, the mine to mine differences are not yet fully documented.

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TABLE 14-2. HALF-WIDTH OF CONFIDENCE INTERVALS COMPARED TO MEDIAN TSP EMISSION FACTOR

Source	Half-width confidence interval/ median emission factor[a]		Relative error predicted in statistical plan (20% risk level)
	80%	95%	
Drills	-0.25, +0.29	-0.35, +0.50	0.20
Blasting	-0.24, +0.30	-0.36, +0.56	0.36
Coal loading	-0.22, +0.30	-0.32, +0.51	0.32
Dozers, coal	-0.15, +0.17	-0.23, +0.30	0.31
Dozers, ovb.	-0.20, +0.25	-0.30, +0.44	0.31
Dragline	-0.15, +0.15	-0.22, +0.27	0.21
Haul truck	-0.18, +0.21	-0.27, +0.36	0.19
Light- and medium-duty veh.	-0.13, +0.16	-0.22, +0.27	0.45
Scraper	-0.16, +0.19	-0.25, +0.34	0.24
Grader	-0.28, +0.38	-0.43, +0.76	0.27
Average	-0.20, +0.24	-0.30, +0.43	0.29

[a] Due to the logarithmic transformation used in the analysis, the intervals are not symmetrical when presented in base_{10}.

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TABLE 14-3. EVALUATION OF WIDELY-USED PARTICULATE EMISSION FACTORS FROM AP-42

Source	Emission factor, EF	Accuracy ranking	No. of tests, n	Precision, $s/EF\sqrt{n}$	Half-width of confidence interval	
					80%	95%
Pulv. coal wet boiler	13A	A	89	0.029	0.04	0.06
Pulv. coal dry boiler	17A	A	34	0.049	0.06	0.10
Spreader stoker	13A	A	17	0.132	0.18	0.28
Asphaltic concrete dryer	45	A	5	0.123	0.19	0.34
Brick curing, gas	0.07	C	3	0.230	0.43	0.99
Brick curing, oil	0.07	C	6	0.204	0.30	0.52
Brick curing, coal	1.30	C	14	0.255	0.34	0.55
Cement kiln, dry	46	B	10	0.206	0.28	0.47
Cement kiln, wet	42.8	B	12	0.236	0.32	0.52
Clay drying	70	A	2	0.018	0.06	0.23
Lime rotary kiln	200	B	4	0.263	0.43	0.84
Refinery FCC	242	A	2	0.785	2.42	9.98
Average			16	0.211	0.28	0.45

Source: Columns 2, 4, and 5, PEDCo Environmental, 1974
Columns 1 and 3, AP-42

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PARTICLE SIZE RELATIONSHIPS

Emission factors were developed specifically for the IP and TSP size ranges, with full data analyses being devoted to each. Because of data analysis problems associated with the very low concentrations of FP, the emission factors for this size fraction were not calculated by profiling, upwind-downwind dispersion equations, etc. Instead, net concentrations for all tests were expressed as a fraction of TPS; the geometric mean fraction for tests of each source was applied to the TSP emission factor for that source to calculate the FP emission factor.

The suspended particulate (SP) emission factors from profiling tests are not actually TSP, but the fraction of total emissions less than 30 µm in aerodynamic diameter. Several references in the literature cite 30 µm as the approximate particle size for 50 percent collection efficiency by the hi-vol sampler. Since TSP is not a clearly defined size distribution, this was the best approximation that could be made from the profiling samples, which collect all particle sizes in the plume nondiscriminately.

From the median emission factors for IP and TSP (Table 13-10), size distributions of emissions appeared to be fairly uniform from source to source. IP and TSP ratios varied from 0.22 to 0.62. The IP to TSP emission factor ratios were similar to those of the IP to TSP net concentrations (shown in Table 12-2), but were not the same because of the independent MLR analyses employed to develop the emission factors for TSP and IP. Also, the emission factor ratios are based on geometric rather than arithmetic means. The IP to TSP ratios were lower than typical in ambient air. However, these ratios were measured at the sources. As the emissions proceed downwind, greater deposition of the TSP fraction should increase the ratio.

The FP and TSP emission factor ratios were derived directly from the geometric mean ratios of their net concentrations, and are the same as were shown in Table 13-8. One of the sources had a ratio that was an apparent anomally--overburn dozers, with an FP to TSP ratio of 0.105. Overburden dozer tests were usually conducted with no visible plume and low downwind concentrations, with accompanying potential for particle size distributions skewed toward smaller particles. With the exception of this source, the range of median FP to TSP ratios by source was 0.017 to 0.040.

For the two sources that constitute the majority of emissions at most mines, haul trucks and scrapers, the average FP to TSP ratios were 0.017 and 0.026, respectively. Because mining emissions are mechanically generated dust, a low percentage of fine particualte would be expected in the TSP emissions. It is not possible to compare the size distribution data from this study with that from previous fugitive dust sampling studies because particle size sampling problems make previous data suspect.

Recognizing that there are still several unresolved problems with generating fine particle data for fugitive dust sources, it is concluded that data from the present study are reasonable based on their consistency and the observed agreement between dichotomous and cascade impactor data.

HANDLING OF DEPOSITION

The emission factors in Table 13-10 were all developed from sampling right at the source. The present test data and information from numerous other studies indicate fairly rapid deposition of these emissions as they move away from the source. Therefore, any ambient air quality analysis using these emission factors should have some provision for considering deposition or fallout.

Different subsets of tests and alternative measurement techniques (dustfall and apparent source depletion as discussed in Section 12) produced greatly varying deposition rates with distance, from no deposition to an average of 79 percent reduction in TSP in the first 100 m. Only a small part of the differences could be explained by parameters such as wind speed and stability class. The net result of the large discrepancies was that test data from the study could not be used to develop a deposition function for application with the emission factors. An empirically-derived function would have been limited to about the first 200 m anyway.

Selection from among available theoretical deposition models is outside the scope of this study, especially since none of the three that were compared with test data matched well in the majority of the tests. Of the three theoretical deposition functions, the tilted plume model is the most simplistic and shows the most rapid deposition over the first several km. The other two models, source depletion and surface depletion, display similar rates and represent supposed options between computational ease and greater accuracy. According to a published review of the two modesl, source depletion overestimates deposition at all distances in comparison with the more accurate surface depletion functions (Horst 1977). However, for the distances and emission heights of interest in mining analyses, the reported differences were minimal (less than 10 percent).

All three deposition modesl require an estimate of settling velocity, a value usually not available. From the brief analysis of observed deposition rates shown in the table on Page 6-28, possible values are 2 cm/s for the IP fraction and 10 cm/s for TSP.

SECTION 15

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF EMISSION FACTORS

Emission facators for 12 significant sources of particulate emissions at surface coal mines were developed from extensive sampling at three different Western mines. Five sampling techniques--exposure profiling, upwind-downwind, balloon sampling, wind tunnel testing, and quasi-stack--were used on the 12 different source types, to best match the advantages of a particular sampling technique to the characteristics of a source. Sampling was conducted throughout the year so that measured emission rates would be representative of annual emission rates. The resulting emission factors are summarized in Table 15-1.

The factors for TSP and IP are in the form of equations with corrections factors for independent variables that were found to have a significant effect (at the 0.146 or better risk level) on each source's emission rates. The ranges of independent variables (correction factors) over which sampling was conducted, and for which the equations is valid, are shown in Table 15-1.

The units for the emission factors and correction factors were selected for ease in obtaining annual activity rates and average parameter values, respectively. The equations are also appropriate for estimating short-term emission rates. For any correction factor that cannot be accurately quantified, a default value equal to its geometric mean (GM) value can be used, see Table 13-9. For each source, the FP emission factor is obtained by multiplying the calculated TSP emission factor by the FP fraction shown in Table 15-1.

The 80 and 95 percent confidence intervals for each of the TPS and IP emission factors, based on sample size and standard deviation, were previously presented in Table 13-10. The average 80 percent confidence interval for TSP was -20 to +24 percent of the median value. By comparing confidence intervals for the present emission factors with those for factors published by EPA in their Compilation of Air Pollutant Emission Factors, AP-42 (1975), it was determined that the present factors should receive an A ranking.

TABLE 15-1. SUMMARY OF WESTERN SURFACE COAL MINING EMISSION FACTORS

Source	TSP/IP	Prediction equation for emission factor	FP fraction of TSP	Units	Range of correction parameters
Drills	TSP	1.3	None	lb/hole	None
Blasting	TSP	$\frac{961\ A^{0.8}}{D^{1.8}\ M^{1.9}}$	0.030	lb/blast	A = area blasted, ft^2 = 1076 to 103,334 M = moisture, % = 7.2 to 38 D = depth of holes, ft = 20 to 135
	IP	$\frac{2550\ A^{0.6}}{D^{1.5}\ M^{2.3}}$			
Coal loading	TSP	$1.16/M^{1.2}$	0.019	lb/ton	M = 6.6 to 38
	IP	$0.119/M^{0.9}$			
Dozers, coal	TSP	$78.4\ s^{1.2}/M^{1.3}$	0.022	lb/h	s = silt content, % = 6.0 to 11.3 M = 4.0 to 22.0
	IP	$18.6\ s^{1.5}/M^{1.4}$			
Dozers, ovb.	TSP	$5.7\ s^{1.2}/M^{1.3}$	0.105	lb/h	s = 3.8 to 15.1 M = 2.2 to 16.8
	IP	$1.0\ s^{1.5}/M^{1.4}$			
Dragline	TSP	$0.0021\ d^{1.1}/M^{0.3}$	0.017	lb/yd^3	d = drop distance, ft = 5 to 100 M = 0.2 to 16.3
	IP	$0.0021\ d^{0.7}/M^{0.3}$			

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TABLE 15-1 (continued)

Source	TSP/IP	Prediction equation for emission factor	FP fraction of TSP	Units	Range of correction parameters
Scrapers	TSP	$(2.7 \times 10^{-5})\ s^{1.3} W^{2.4}$	0.026	lb/VMT	s = 7.2 to 25.2 W = vehicle weight, tons = 36 to 64
	IP	$(6.2 \times 10^{-6})\ s^{1.4} W^{2.5}$			
Graders	TSP	$0.040\ S^{2.5}$	0.031	lb/VMT	S = vehicle speed, mph = 5.0 to 11.8
	IP	$0.051\ S^{2.0}$			
Light- and medium-duty vehicles	TSP	$5.79/M^{4.0}$	0.040	lb/VMT	M = 0.9 to 1.7
	IP	$3.22/M^{4.3}$			
Haul trucks	TSP	$0.0067\ w^{3.4} L^{0.2}$	0.017	lb/VMT	w = average number of wheels = 6.1 to 10.0 L = silt loading, g/m^2 = 3.8 to 254.0
	IP[a]	$0.0051\ w^{3.5}$			

[a] Silt loading was not a significant correction parameter for the IP fraction.

Emission factors were reported for three size ranges--fine particulate (<2.5 μm), inhalable particulate (<15 μm), and total suspended particulate (no well-defined upper cut point, but approximated as 40 μm). The fairly consistent ratios of FP and IP to TSP for different sources indicate that fugitive dust sources at mines all have similar size distributions. Most of the particle sizing data were obtained with dichotomous samplers.

The emission factors in Table 15-1 are all for uncontrolled emission rates. Control efficiencies of a few control measures were estimated by testing, as reported in Table 12-5. These control efficiencies should be applied to the calculated emission factors in cases where such controls have been applied or are anticipated. However, many of the dust-producing operations are not normally controlled.

The design and field work for this study have received far more review and quality assurance checks than any similar projects in air pollution control. However, because of the large variations in emission rates over time for mining sources and the imprecision of key sampling instruments while sampling in dense dust plumes, the added care in conducting the study did not result in appreciable better sampling data with which to develop the emission factors.

LIMITATIONS TO APPLICATION OF EMISSION FACTORS

The emission factors are designed to be widely applicable through the use of correction factors, but they still have some limitations which should be noted:

1. The factors should be used only for estimating emissions from Western coal mines. There is no basis for assuming they would be appropriate for other types of surface mining operations or for coal mines located in other geographic areas without further evaluation.

2. Correction factors used in the equations should be limited to values within the ranges tested (see Table 15-1). This is particularly important for correction factors with a large exponent, because of the large change in the resulting emisison factor associated with a change in the correction factor.

3. These factors should be combined with a deposition function for use in ambient air quality analyses. After evaluation of the deposition data from this study, no empirical deposition function could be developed. Any function subsequently developed from these data should have provision for further deposition beyond the distance of sampling in this study (100-200 m).

4. The factors were obtained by sampling at the point of emission and do not address possible reductions in emissions in order to account for dust being contained within the mine pit.

5. As with all emission factors, these mining factors do not assure the calculation of an accurate emission value from an individual operation. The emission estimates are more reliable when applied to a large number of operations, as in the preparation of an emission inventory for an entire mine. The emission factors are also more reliable when estimating emissions over the long term because of short-term source variation.

6. Appropriate adjustments shoud be made in estimating annual emissions with these factors to account for days with rain, snow cover, temperatures below freezing, and intermittent control measures.

7. The selection of mines and their small number may have biased final emission factors, but the analysis did not indicate that a bias exists.

8. The confidence intervals cited in Table 13-10 estimate how well the equations predict the measured emission rates at the geometric mean of each correction factor. For predicting emission rates from a mine not involved in the testing or for predicting rates under extreme values of the stated range of applicability of the correction factors, confidence intervals would be wider.

9. Error analyses for exposure profiling and upwind-downwind sampling indicated potential errors of 30 to 35 percent and 30 to 50 percent, respectively, independent of the statistical errors due to source variation and limited sample size.

10. Geometric means were used to describe average emission rates because the data sets were distributed lognormally rather than normally. The procedure makes comparison with previous emission factors difficult, because previous factors were all arithmetic mean values.

11. Wind erosion emission estimates should be restricted to calculation of emissions relative to other mining sources; they should not be included in estimates of ambient air impact.

REMAINING RESEARCH

A comprehensive study such as the present one that has evaluated alternative sampling and analytical techniques is bound to identify areas where additional research would be valuable. Also, some inconsistencies surface during the data analysis phase, when it is too late to repeat any of the field studies. Therefore, a brief list of unresolved problems has been compiled and is presented here.

1. Sampling at Midwestern and Eastern coal mines is definitely needed so that emission factors applicable to all surface coal mines are available.

2. A resolution of which deposition function is most accurate in describing fallout of mining emissions is still needed. Closely related to this is the need for a good measurement method for deposition for several hundred meters downwind of the source (dustfall is recommended for measurements up to 100 or 200 m). In the present study, both the source depletion and dustfall measurement methods were found to have deficiencies.

3. A method for obtaining a valid size distribution of particles over the range of approximately 1 to 50 µm under near-isokinetic conditions is needed for exposure profiling. The method should utilize a single sample for sizing rather than building a size distribution from fractions collected in different samplers.

4. The emission factors presented herein should be validated by sampling at one or more additional Western mines and comparing calculated values with the measured ones.

5. Standardized procedures for handling dichotomous filters should be developed. These should address such areas as numbering of the filters rather than their petri dishes, proper exposure for filters used as blanks, transporting exposed filters to the laboratory, equilibrating filters prior to weighing, and evaluation of filter media other than Teflon for studies where only gravimetric data are required.

6. One operation determined in the study design to be a significant dust-producing source, shovel/truck loading of overburden, was not sampled because it was not performed at any of the mines tested. Sampling of this operation at a mine in Wyoming and development of an emission factor would complete the list of emission factors for significant sources at Western coal mines (See Table 2-1).

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7. Further study of emission rate decay over time from eroding surfaces is needed. In particular, more information should be obtained on the effect of wind gusts in removing the potentially erodible material from the surface during periods when the average wind speed is not high enough to erode the surface.

8. More testing of controlled sources should be done so that confidence in the control efficiencies is comparable to that for the uncontrolled emission rates.

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SECTION 16

REFERENCES

Bagnold, R. A. The Physics of Blown Sand and Desert Dunes, Methuen, London. 1941.

Chalekode, P. K. and J. A. Peters. Assessment of Open Sources. Presented at Third National Conference on Energy and the Environment, College Corner, Ohio. October 1, 1975.

Chepil, W. S. and N. P. Woodruff. The Physics of Wind Erosion and Its Control. Advances in Agronomy, Vol. 15, A. G. Norman (Ed.), Academic Press, New York. 1963

Colorado Department of Health, Air Pollution Control Division. Fugitive Emission Factors. Denver, Colorado. 1980.

Cowherd, C., K. Axetell, C. Guenther, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-74-037. 1974.

Cowherd, C., Jr., R. Bohn, and T. Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation. Prepared by Midwest Research Institute for U.S. Environmental Protection Agency. Publication No. EPA-600/2-79-103. May 1979.

Draper, N. R. and H. Smith. Applied Regression Analysis. John Wiley and Sons, New York, New York. 1965.

Dyck, R. I. and J. Stukel. Fugitive Dust Emissions from Trucks on Unpaved Roads. Environmental Science and Technology, 10(10):1046-48. 1976.

Environmental Research and Technology. Air Pollutant Emissions in the Northwest Colorado Coal Development Area. Prepared for Bureau of Land Management, Denver, Colorado. Westlake Village, California. 1975

Gillette, D. A., and I. H. Blifford, Jr. Measurement of Aerosol Size Distribution and Vertical Fluxes of Aerosols on Land Subject to Wind Erosion. J. of Applied Meteorology, 11:977. 1972.

Gillette, D. A Wind Tunnel Simulation of the Erosion of Soil: Effect of Soil Texture, Wind Speed, and Soil Consolidation on Dust Production. Atmospheric Environment, 12:2309. 1978.

Hald, A. Statistical Theory with Engineering Applications. John Wiley and Sons, New York, New York. 1952.

Hesketh, H. E. Fine Particles in Gaseous Media. Ann Arbor Science Publishers, Ann Arbor, Michigan. 1977.

Horst, T. W. A Surface Depletion Model for Deposition from a Gaussian Plume. Atmospheric Environment (Great Britain). 11:41-46, 1977

Jutze, G. and K. Axetell. Investigations of Fugitive Dust, Volume I--Sources, Emissions, and Control. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-450/3-74-036a. June 1974.

Kalika, P. W., R. E. Kenson, and P. T. Bertlett. Development of Procedure for the Measurement of Fugitive Emissions. Prepared by the Research Corporation of New England for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/2-76-284. December 1976.

McCalden, R. O. and J. Heidel. Particulate Emissions from Vehicle Travel Over Unpaved Roads. Paper presented at the 71st Annual Meeting of the Air Pollution Control Association in Houston, Texas. June 1978.

Mercer, T. T. Aerosol Technology in Hazard Evaluation. Academic Press, New York, New York. 1973.

Midwest Research Institute. Fugitive Emisisons from Integrated Iron and Steel Plants. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-600/2-78-050. March 1978.

Midwest Research Institute. Error Analysis for Exposure Profiling. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. October 1979.

Mitchell, E., Jr., and K. O. Timbre. Atmospheric Stability Class from Horizontal Wind Fluctuation. Paper 79-29.2 Presented at the 72nd Annual Meeting of the Air Pollution Control Association, Cincinnati, Ohio. June 24-29, 1979.

Monsanto Research Corporation. Fugitive Dust from Mining Operations, Final Report, Task No. 6. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. May 1975.

Natrella, M. G. Experimental Statistics. U.S. Department of Commerce, National Bureau of Standards, Washington, DC. NBS Handbook 91. August 1963.

Nie, N. H., et al. Statistical Package for the Social Sciences, Second Edition. McGraw-Hill, Inc., New York, New York. 1975.

PEDCo Environmental, Inc. Source Inventory and Emission Factor Analysis, Volume I. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. September 1974.

PEDCo Environmental, Inc. Emission Estimates for the Berkeley Pit Operations of Anaconda Company. Prepared for Montana Air Quality Bureau, Helena, Montana. September 1975.

PEDCo Environmental, Inc. Evaluation of Fugitive Dust Emissions from Mining. Task 1 Report: Identification of Fugitive Dust Sources Associated with Mining. Prepared for U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati, Ohio. April 1976.

PEDCo Environmental, Inc. Error Analysis for Upwind-Downwind Sampling. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. October 1979.

PEDCo Environmental, Inc. and Midwest Research Institute. Comprehensive Study Design--Emission Factors and Control Technology for Fugitive Dust from Mining Sources (Third Draft). Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. August 1979.

PEDCo Environmental, Inc. Impact of Stone Quarry Operations on Particulate Levels (Draft). Illinois Institute of Natural Resources, Chicago, Illinois. September 1980.

Reider, P. and C. Cowherd. Inhalable Particulate Emission Factor Assessment and Development. Prepared by Midwest Research Institute for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. April 1979.

Snedecor, G. W. Statistical Methods. Fourth Edition. The Iowa State College Press, Ames, Iowa. Chapter 13, Multiple Regression and Convariance. 1946.

Stockham, J. D., Editor, Particle Size Analysis. Ann Arbor Science Publishers, Ann Arbor, Michigan. 1977.

Turner, D. B. Workbook of Atmospheric Dispersion Estimates. U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio. Publication Number AP-26. May 1970.

U.S. Bureau of Mines. Reserve Base of U.S. Coals by Sulfur Content. Part 2, The Western States. Publication No. IC8693. Washington, DC. 1977

U.S. Department of Energy, Energy Information Administration. Bituminous Coal and Lignite Production and Mine Operations--1978. Publication No. EOE/EIA-0118(78). Washington, D.C. June 1980.

U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. Second Edition. Research Triangle Park, North Carolina. Publication No, AP-42. April 1975.

U.S. Environmental Protection Agency. Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions. Research Triangle Park, North Carolina. Publication No. EPA-450/3-77-101. March 1977a.

U.S. Environmental Protection Agency. Quality Assurance Handbook for Air Pollution Measurement Systems. Volume II: Ambient Air Specific Methods. Research Triangle Park, North Carolina. Publication No. EPA-600/4-77-027a. May 1977b.

U.S. Environmental Protection Agency. Cascade Impactor Data Reduction with SR-52 and TI-59 Programmable Calculators. Research Triangle Park, North Carolina. Publication No. EPA-600/7-78-226. November 1978b.

U.S. Environmental Protection Agency. EPA Region VIII Interim Policy Paper on Air Quality Review of Surface Mining Operations. Denver, Colorado. January 1979.

Wedding, James B. Ambient Aerosol Sampling: History, Present Thinking and a Proposed Inlet for Inhalable Particulate Matter. Paper presented at the Air Pollution Control Association Specialty Conference, Seattle, Washington. April 23, 1980.

Wyoming Department of Environmental Quality. Wyoming Air Quality Maintenance Area Analysis. Appendix B: Development of a Particulate Emission Factor for Surface Mining in the Powder River Basin of Wyoming. Cheyenne, Wyoming. May 1976.

Wyoming Department of Environmental Quality. Memorandum on Fugitive Dust Emission Factors. Cheyenne, Wyoming. January 24, 1979.

Zimmerman, J. R., and R. S. Thompson. User's Guide for HIWAY, A Highway Air Pollution Model. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. EPA-650/4-74-008. February 1975.

APPENDIX A

STEPWISE MULTIPLE LINEAR REGRESSION

Multiple linear regression (MLR) is a statistical technique for estimating expected values of a dependent variable, in this case particulate emission rates, in terms of corresponding values of two or more other (independent) variables. MLR uses the method of least squares to determine a linear prediction equation from a set of simultaneously-obtained data points for all the variables. The equation is of the form:

$$\text{Emission rate} = B_1x_1 + B_2x_2 + \ldots + B_nx_n + \text{constant}$$

where x_1 to x_n = concurrent quantitative values for each of the independent variables

B_1 to B_n = corresponding coefficients

The coefficients are estimates of the rate of change in emission rates produced by each variable. They can be determined easily by use of an MLR computer program or with a programmed calculator. Other outputs of the MLR program are:

1. A correlation matrix. It gives the simple correlation coefficients of all of the variables (dependent and independent) with one another. It is useful for identifying two interdependent (highly correlated--either positive or negative) variables (two variables that produce the same effect on emission rates), one of which should be eliminated from the analysis.

2. The multiple correlation coefficient (after addition of each independent variable to the equation). The square of the multiple correlation coefficient is the fraction of total variance in emission rates that is accounted for by the variables in the equation at the point.

3. Residual coefficient of variability. This is the standard deviation of the emission rates predicted by the equation (with the sample data set) divided by the mean of the predicted emisison rates, expressed as a percent. If a variable eliminates some sample variance, it will reduce the standard deviation and hence the relative coefficient of variability.

4. Significance of regression as a whole. This value is calculated from an F test by comparing the variance accounted for by the regression equation to the residual variance. A 0.05 significance level is a 1 in 20 change of the correlation being due to random occurrence.

5. Significance of each variable. This is a measure of whether the coefficient (B) is different than 0, or that the relationship with the dependent variable is due to random occurrence. Variables that do not meet a prespecified significance level may be eliminated from the equation.

6. Constant in the equation.

The multiple correlation coefficient, unlike the simple correlation coefficient, is always positive and varies from 0 to 1.0. A value of zero indicates no correlation and 1.0 means that all sample points lie precisely on the regression plane. Because of random fluctuations in field data and inability to identify all the factors affecting emission rates, the multiple coefficient is almost never zero even when there is no real correlation and never 1.0 even when concentrations track known variables very closely. Therefore, it is important to test for statistical significance.

The form of MLR in the program used in this study was stepwise MLR. Variables were added to the equation in order of greatest increase in the multiple correlation coefficient, with concentrations then adjusted for that variable and regressed against the remaining variables again. The procedure can be ended by specifying a maximum number of variables or a minimum F value in the significance test. In subsequent runs, the order of entry of variables was sometimes altered by specifying that a certain variable be entered first or last.

In order to satisfy the requirement that the variables be quantitative, some were input as dummy variables with only two possible values. For example, in an MLR run of all blasts, one variable had a value of 0 for all coal blasts and 1 for all overburden blasts. The significance of this variable determined whether there was a significant difference between coal and overburden blast emission rates, and the B value was a direct measure of the difference between the two average emission rates after adjustment for other variables in the MLR equation.

A statistically significant regression relationship between independent variables and particulate emission rates is no indication that the independent variables cause the observed changes in emission rate, as both may be caused by a neglected third variable.

APPENDIX B

CALCULATIONS FOR CONFIDENCE AND PREDICTION INTERVALS

The computational procedures for confidence and prediction intervals for emission rates are illustrated in this appendix using TSP emission rates for coal loading as a function of moisture content (M). The data are tabulated in Table B-1 for convenience, that is, the moisture, %, and the observed emission rate, lb/ton, for each of the 24 tests. The arithmetic average ($\overline{X}$), standard deviation (s), and geometric mean (GM) are given at the bottom of the table.

Confidence Interval

The computational procedure for confidence intervals is as follows:

1. The first step in the analysis is to perform a linear regression analysis. In this example, the dependent variable is the logarithm of the emission rate (ln E) and the independent variable is the logarithm of moisture (ln M). (Natural logarithms, i.e., to base e are used throughout this discussion).

2. The prediction equation for the mean ln E is given by:

$$\widehat{\ln E} = b_o + b_1 (\ln M - \overline{\ln M}) \qquad \text{(B-1)}$$

where

$\widehat{\ln E}$ is the predicted mean for ln E as a function of M

b_o, b_1 are the regression coefficients estimated from the data

ln M is the ln of moisture content

$\overline{\ln M}$ is the arithmetic average of ln M ($\overline{\ln M} = 2.882$ for this example)

TABLE B-1. TSP EMISSION RATES FOR COAL LOADING, LB/TON

Test number	Moisture, %	Observed emission, lb/ton
1	22	0.0069
2	22	0.0100
3	38	0.0440
4	38	0.0680
5	38	0.0147
6	38	0.0134
7	38	0.0099
8	38	0.0228
9	38	0.0206
10	38	0.0065
11	11.9	0.1200
12	11.9	0.0820
13	11.9	0.0510
14	18	0.0105
15	18	0.0087
16	18	0.0140
17	12.2	0.0350
18	11.1	0.0620
19	11.1	0.0580
20	11.1	0.1930
21	11.1	0.0950
22	6.6	0.0420
23	6.6	0.3580
24	6.6	0.1880
$\bar{X}$	21.42	0.0639
s	12.64	0.0819
GM	17.85	0.0337

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3. The following results are obtained from the MLR (multiple linear regression) computer printout for subsequent use in computation.

The prediction equation is:

$$\widehat{\ln E} = -3.385 - 1.227\ (\ln M - 2.882)$$

Note: Almost all computer printouts give the prediction equation in the form:

$$\widehat{\ln E} - 0.152 - 1.227 \ln M \qquad \text{(B-2)}$$

that is, the constants are combined into one term (0.152 = -3.385 + 1.227 x 2.882). The form provided above in Equation B-1 is simpler for the computation of the confidence and prediction intervals. In the above form b_o is the average of the ln E (ln E), which is available in the printout.

In addition, one obtains:

$r^2 = 0.451$ (the square of the correlation coefficient)

$s^2 = 0.764$, $s = 0.874$ (the standard deviation of the logarithm of the observed emission rates about the corresponding predicted ln values).

The variance of the estimated regressions coefficients are read or computed from data listed in the computer printout:

$$s_o^2 = \text{estimated variance of } b_o = \frac{s^2}{n}$$

$$s_o^2 = \frac{0.764}{24} = 0.0318$$

$$s_1^2 = \text{estimated variance of } b_1$$

$$= (0.2523)^2 = 0.0637$$

The value of s_1^2 can be computed by formulas given in Hald.[1] In this case $s_1 = 0.2523$ is given in the computer printout for the purpose of testing the significance of the estimated coefficient b_1.

4. The standard deviation of ln E is:

$$s(\widehat{\ln E}) = [s_o^2 + s_1^2\ (\ln M - \ln M)^2]^{1/2} \qquad \text{(B-4)}$$

$$= [0.0318 + 0.0637\ (\ln M - 2.882)^2]^{1/2} \qquad \text{(B-5)}$$

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5. The geometric mean of the emission factor E is given by:

$$\exp\{\ln \hat{E}\} \qquad \text{(B-6)}$$

and this estimates the median value of E as a function of M. It should be noted that the mean value of E is estimated by:

$$\exp\{\ln \hat{E} + \tfrac{1}{2} s^2\} \qquad \text{(B-7)}$$

Throughout the remainder of this discussion the GM values are used as estimates of the corresponding median emission value.

6. The confidence interval for the median value of E as a function of M is obtained by:

$$\exp\{\ln \hat{E} \pm t\, s(\ln \hat{E})\} \qquad \text{(B-8)}$$

where $\ln \hat{E}$ and $s(\ln \hat{E})$ are obtained from Equations B-2 and B-4, respectively, and t is read for the desired confidence level from a standard t table available in almost any statistical test (e.g., Hald's tables[2]). Substituting values of M in Equation (B-8) (and B-2 and B-4) yields the results plotted in Figure 13-1 and repeated here for convenience as Figure B-1. One must not go beyond the limits for observed M because there are no data or theory to support the extrapolation.

The 95 percent confidence limits for the median E at the GM of M (i.e., exp {2.882} = 17.85%) are:

$$\exp\{\ln \hat{E} \pm 2.074\, s(\ln \hat{E})\}$$

where

$$\ln \hat{E} = -3.385$$

$$s(\ln \hat{E}) = [0.0318 + 0.0637(0)]^{\frac{1}{2}} = 0.178$$

and the upper (UCL) and lower (LCL) 95 percent confidence limits are:

$$95\%\ \text{Limits} \begin{cases} \text{UCL} = 0.049\ \text{lb/ton} \\ \text{LCL} = 0.023\ \text{lb/ton} \end{cases}$$

Similarly, the 80 percent confidence limits are given by:

$$\exp\{\ln \hat{E} \pm 1.321\, s(\ln \hat{E})\}$$

or

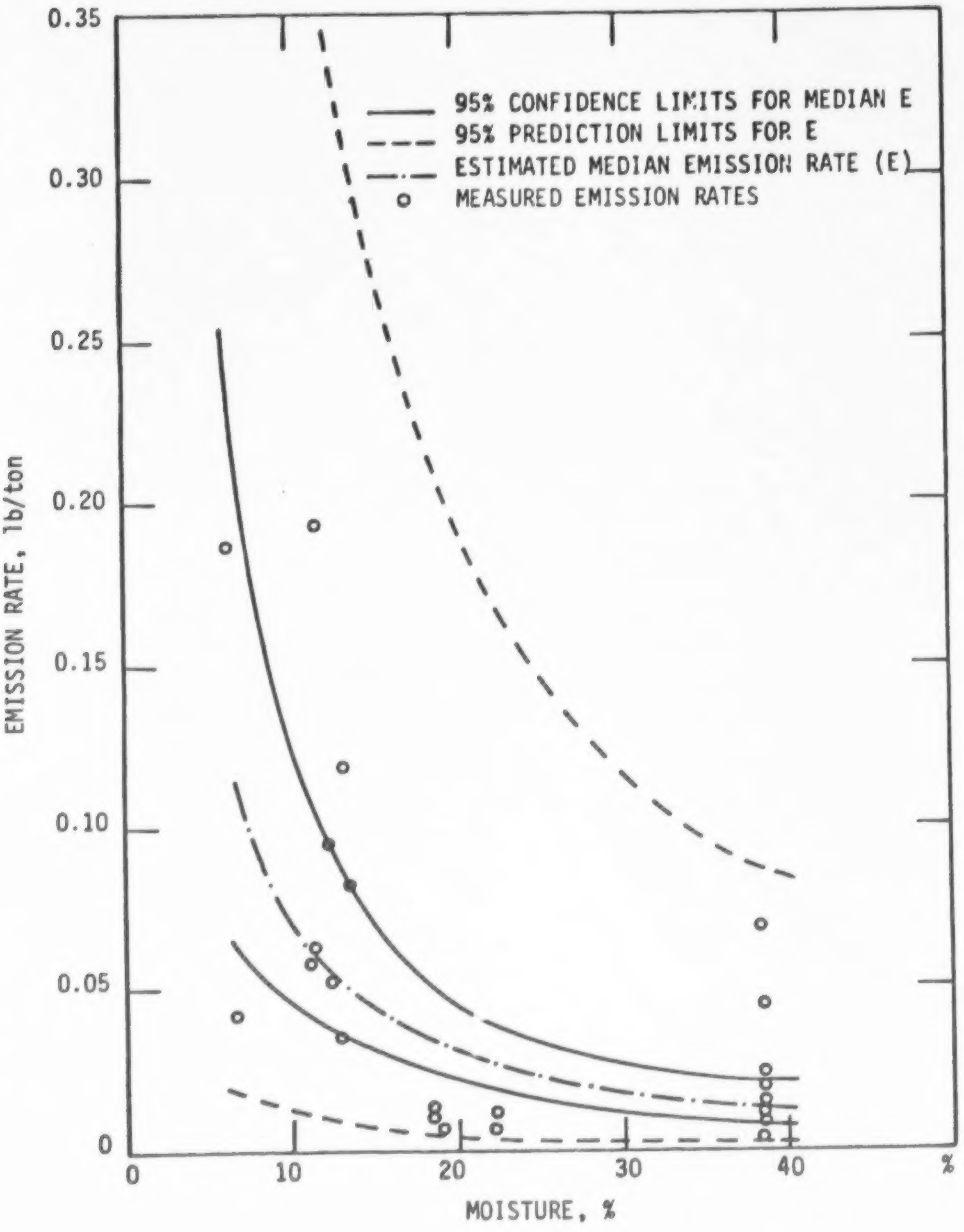

Figure B-1. Confidence and prediction intervals for emission factors for coal loading.

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$$80\%\ \text{Limits}\ \begin{cases}\text{UCL} = 0.043\ \text{lb/ton}\\ \text{LCL} = 0.027\ \text{lb/ton}\end{cases}$$

The median value is:

$$\exp\{\widehat{\ln E}\} = 0.0339$$

The above confidence limits are also expressed below as percentages of the predicted median, 0.0339.

$$95\%\ \text{Limits}\ \begin{cases}\text{UCL} = 1.45 \times \text{predicted median}\\ \text{LCL} = 0.68 \times \text{predicted median}\end{cases}$$

$$80\%\ \text{Limits}\ \begin{cases}\text{UCL} = 1.27 \times \text{predicted median}\\ \text{LCL} = 0.80 \times \text{predicted median}\end{cases}$$

These limits are a measure of the quality of the prediction of the median emission E for given M on the basis of the data from the three mines. The widths of these confidence intervals are consistent with data typically reported by EPA as stated in Section 15.

One application of these limits would be to estimate the median annual emissions based on a large number of tons of coal loaded at the mine with GM moisture content of 17.85 percent. If the moisture content deviates from this value (17.85%), it is necessary to calculate the interval at the appropriate value of M using Equation (B-8).

Because of the complication in presenting the complete results for all sources and pollutants as in Figure B-1, the confidence intervals are presented only for the correction factors (M in this example) at their GM value. Table 13-10 contains these data for all sources and pollutants.

Prediction Interval

The confidence interval previously described gives a measure of the quality of the data and of the predicted median which is applicable only for a large number of operations relative to the emission factor of interest. In the example in this appendix, this would imply a large number of coal loading operations (or tonnage of coal loaded). There will be applications in which the number of operations is not large and a prediction interval is desired which is expressed as a function of the number of operations. The calculation of this interval follows the first three steps of that for the confidence interval; the subsequent steps, starting with Step 4, are as follows:

4. The standard deviation of an individual predicted ln emission factor is:

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$$s(\ln E) = [s^2(\ln \hat{E}) + s^2]^{1/2}$$

$$= [\frac{s^2}{n} + s_1{}^2 (\ln M - \overline{\ln M})^2 + s^2]^{1/2} \qquad \text{(B-9)}$$

For the coal loading data,

$$s(\ln E) = [0.0318 + 0.0637 (\ln M - 2.882)^2 + 0.764]^{1/2} \qquad \text{(B-10)}$$

5. The prediction interval for an emission factor E is:

$$\exp \{\ln \hat{E} \pm t\ s(\ln E)\}$$

For the coal loading data, this interval is given by:

$$\exp \{\ln \hat{E} \pm t[0.0318 + 0.0637 (\ln M - 2.882)^2 + 0.764]^{1/2}\} \qquad \text{(B-11)}$$

The results are plotted in Figure B-1 as a function of M. For the GM of M (i.e., ln M = 2.882), the prediction limits are:

95% Limits{ UPL = 0.215 lb/ton
LPL = 0.005 lb/ton

80% Limits{ UPL = 0.110 lb/ton
LPL = 0.010 lb/ton

6. The prediction interval for an individual value is obviously much wider than the corresponding confidence interval for a median value. If it is desired to predict the emissions based on a number of operations, say N (e.g., N tons of coal), the confidence interval is given by

$$\exp\{\ln \hat{E} \pm t\ [s^2(\ln E) + \frac{s^2}{N}]^{1/2}\} \qquad \text{(B-12)}$$

that is, the last term in Equation B-9 is divided by N instead of 1. Note that as N becomes large this result simplifies to that of Equation (B-8).

Test for Normality

One of the major assumptions in the calculations of the confidence and prediction intervals is that the ln residuals (deviations of the ln E from ln E) are normally distributed, hence the lognormality assumption for the original (and transformed data). A check for normality was performed on the ln residuals for six data sets with the largest number of data values. In two of the six cases the data deviated from normality (these two cases were TSP and IP emissions for Blasting). Based on these results, the lognormal assumption was made because of both computational convenience and adequate approximation for most of the data.

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REFERENCES

1. Hald, A. Statistical Theory with Engineering Applications. John Wiley and Sons, Inc. New York. 1952

2. Hald, A. Statistical Tables and Formulas. John Wiley and Sons, Inc. New York. 1952.

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